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THE

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JANUARY-FEBRUARY, 1893.

ON THE PRE-CAMBRIAN ROCKS OF THE BRITISH ISLES.

DURING the last twenty years much has been written about the "pre-Cambrian" rocks of the British Isles. Unfortunately when attention began to be sedulously given to the study of these ancient formations, the problems of metamorphism were still a hundred fold more obscure than they have since become; the aid of the microscope had not been seriously and systematically adopted for the investigation of the crystalline schists, and geologists generally were still under the belief that the broad structure of these schists could be treated like those of the sedimentary rocks, and be determined by rapid traverses of the ground. We have now painfully discovered that these older methods of observation were extremely crude, and that the work performed in accordance with them is now of little interest or value save as a historical warning to future generations of geologists. Geological literature has meanwhile been burdened with numerous contributions which remain as a permanent incubus on our library shelves.

It may serve a useful purpose at the present time in possibly aiding those who are engaged in the study of the oldest rocks of North America, if I place before them, as briefly as possible, the main facts which in my opinion have now been satisfactorily proved regarding the corresponding rocks of Britain, and if I indicate at the same time some of the more probable inferences in those cases where the facts, at present known, do not warrant a definite conclusion.

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ical record. They are certainly both pre-Cambrian, bu must belong to widely separated eras, and must have bee duced by entirely different processes. If it is proposed to the gneisses as "Archæan," we must refuse to include the donian strata in the same section of pre-Cambrian time. much uncertainty exists as to the application of this term Ar examples are so multiplying wherein what was supposed the oldest and truly Archæan rock is found to be intrus rocks that were taken to be of much younger date, and th such slender grounds for correlating the so-called Ar rocks of one country with those of another, that I prefer present, at least, not to use the term at all. Let me very state some of the main characteristics of the two sharpl trasted rock-systems of the north-west of Scotland.

The oldest gneiss of that region was originally called ' isian" by Murchison, from its large development in the Isl Lewis, and I think it would be, for the present at least, an tage to retain this geographical appellation. At firs "fundamental gneiss" was thought to be a comparatively formation, and the general impression probably was that it be regarded as a metamorphic mass, produced mainly fro alterations of very ancient stratified rocks. Its foliation- were believed to be those of original deposit which by terr disturbance had been thrown into numerous plications and gated puckerings. But a detailed study of this primeva has revealed in it a far more complicated structure. Th posed bedding-planes have been ascertained to have noth do with sedimentary stratification, and the gneiss has resolved into a complex series of eruptive rocks, varying f highly basic to an acid type, and manifestly belonging to ent times of extrusion. With the exception of one distr which I shall immediately refer, no part of the whole regi examined has revealed to the rigid scrutiny of my colleag the Geological Survey, any trace of rocks which ca regarded as probably of other than igneous origin. It i that our researches have been hitherto confined to the ma

of Scotland, the large area of the Outer Hebrides, which consists of similar gneisses, remaining to be explored. It is therefore possible that indisputable evidence of an ancient sedimentary series through which the gneiss was originally protruded, may yet be discovered in the unexplored islands. But taking the gneiss as at present known in Sutherland and Rosshire, we find it to be generally coarse in texture, rudely foliated, and passing sometimes into massive types in which foliation is either faintly developed or entirely absent. Much of this gneiss is considerably more basic than the more typical rocks to which the term gneiss was formerly restricted. It consists of plagioclase felspar with pyroxene, hornblende, and magnetite, sometimes with blue opalescent quartz, and sometimes with black mica. These predominant minerals are segregated in different proportions in the different bands, some bands consisting mainly of pyroxene or hornblende, with little or no plagioclase, others chiefly of plagioclase, with small quantities of the ferro-magnesian minerals and quartz, others of plagioclase and quartz, others of magnetite. This separation of mineral constituents can hardly be attributed to mere mechanical deformation. It rather resembles the segregation layers which may be studied in intrusive sills and other deep-seated masses of eruptive material, and which are obviously due to a process of separation that went on while the igneous magma was still in a liquid or viscous condition. At the same time it is manifest that extensive dynamical changes have affected the rocks since the appearance of this original banded structure.

There is further evidence that beside the original eruptive masses, which for want of any means of discriminating their relative dates of protrusion must in the meantime be regarded as belonging to one eruptive period, other portions of igneous material have been subsequently and at successive epochs, after the first mechanical deformations, injected into the body of the original gneiss. These consist of dykes of basalt and dolerite, followed by still more basic peridotites and picrites, and lastly by emanations from a distinctly acid magma in the form of granites.

The oldest or doleritic dykes form a wonderful featur(gneiss, from their abundance, persistence and uniformity (in a west-northwest direction. They have no parallel in Geology until we reach the crowded dykes of older] time.

Throughout this remarkable complex of eruptive n though its different portions present many features that compared with those of intrusive bosses and sheets belon later geological periods, there is no trace of any su volcanic manifestation. No tuffs or agglomerates or lavas have been detected, such as might serve to indic ejection of volcanic materials to the surface. All the phe of the Lewisian gneiss point to the consolidation of succ protruded portions of eruptive material at some depth wi crust.

Nevertheless it may yet be possible to show that the seated masses have been injected into rocks of older d of sedimentary origin, and that they have communicat the surface in true volcanic eruptions. I have already to one limited area where various rocks exist, distinctly d from the prevalent types in the Lewisian gneiss. In t which is traversed by the long valley of Loch Maree in Rosshire, there occur clay-slates, fine mica schists, g schists, and saccharoid limestones. These rocks remin some of the prevalent members of a series of metamo sediments. The minerals enclosed in the marbles are ju as might be expected in the metamorphic aureole of a boss, piercing limestone. But the relations of this group (to the ordinary gneiss of the region are not quite so (could be desired, though they seem to point to thes(being surrounded by and enclosed within the gneiss.

The detailed field-work of the officers of the Geologi(vey has made known the remarkable amount of mec deformation which the various rock-masses composi Lewisian gneiss have undergone. These rocks have bee pressed, crushed, and drawn out, until what were original

sive crystalline protrusions have been converted into perfect schists. The dykes of dolerite have been transformed into hornblende-schists and the granitic pegmatites have been reduced to a kind of powder which has been rolled out so as to simulate the flow-structure of a lava. There is evidence that most, if not all, of this dynamical change was effected long before the deposition of the Torridonian series, for the latter rests in nearly horizontal sheets, with a strong unconformability upon the crushed and sheared gneiss.

Torridon Sandstone. This group of rocks covers only a limited area in the north-west of Scotland, but it must once have spread over a far more extensive region. It reaches a thickness, as I have said, of 8,000 or 10,000 feet, and consists almost wholly of dull, purplish-red sandstones, often pebbly, and bands of conglomerate. Dark grey shales, already alluded to as occurring towards the base of the series, are repeated also in the highest visible portion, and have yielded tracks of what seem to have been annelids and casts of nail-like bodies which may have been organic. I have said that the Torridonian deposits which were classed by Murchison as Cambrian, have been proved by the discovery of the *Olenellus* zone in an unconformable position above them, to be of pre-Cambrian age. Except along the line of disturbance to which I shall immediately refer, these strata are quite unaltered. Indeed, in general aspect they look as young as the old red sandstones with which Hugh Miller identified them. It is at first hard to believe that such flat undisturbed sandstones are of higher antiquity than the very oldest Palæozoic strata which are so generally plicated and cleaved.

The interval of time between the deposition of the Torridon Sandstone and of the overlying Cambrian formations must have been of enormous duration, for the unconformability is so violent that the lowest Cambrian strata, not only transgressively overspread all the Torridonian horizons, but even lie here and there directly on the old gneiss, the whole of the intervening thick mass of sandstone having been there removed by previous denudation. At Durness, in the north of Sutherland, about 2000 feet of

Cambrian (possibly in part Lower Silurian) strata c traced, the lower portion consisting of quartzites, the c and upper parts of various limestones, sometimes abun fossiliferous. Nowhere else in the north of Scotland thick a mass of early Palæozoic rocks be seen. Elsewhe limestones have been in large measure replaced by a co group of schistose rocks which rest upon the Cambrian s and like them dip, generally at gentle angles, towards the It was the opinion of Murchison, and was commonly adı by geologists, that these overlying schists represented a group of sediments, which, originally deposited continu after the limestones, had been subsequently altered into present condition by regional metamorphism. They were ously named the "Eastern schists," the "younger gneiss, "gneissose and quartzose flagstones." Nicol, who at shared the general opinion regarding them, afterwards tained that they did not belong to a later formation tha limestones, but were really only the old gneiss, brought up from beneath by enormous dislocations and over-thrusts. now know from the labors of Professor Lapworth and the of of the Geological Survey, that Murchison and Nicol had seized on an essential part of the problem, but that bc them had missed the true solution. Murchison was in er regarding his younger gneiss as a continuous sequenc altered sedimentary rocks conformably resting on the Cam (or to use his terminology, Lower-Silurian) formations. he sagaciously observed the coincidence of dip and s between the schists and sedimentary rocks below them inferred that this coincidence, traceable for many lea proved that the metamorphism which had given these sc their structure must have taken place after the deposition o Durness limestones. Nicol, on the other hand, with great in recognized that there was no continuous sequence above t limestones, but that masses of the old gneiss had been tl over them by gigantic faults. But he failed to see that no faults would account for the coincidence between the struc

lines just referred to in the Cambrian strata, and in the overlying schists, and that the general tectonic structures and lithological characters of the eastern schists differed in many respects from those of the Lewisian gneiss.

The problems in tectonic geology presented by the complicated structures of the northwest of Scotland have been ably worked out by the officers of the Geological Survey, to whose report in the *Quarterly Journal of the Geological Society* for 1888, I would refer for full details. It has been shown that, besides stupendous dislocations and horizontal displacements, the rocks have been cut into innumerable slices which have been driven over each other from the eastward, while at the same time there has been such a general shearing of the whole region that for many hundreds of square miles the original rock-structures have been entirely effaced, and have been replaced by new divisional planes, which, when they approach the underlying Cambrian strata, are roughly parallel with the bedding planes of these strata.

In this region, therefore, we have striking proofs of a stupendous post-Cambrian regional metamorphism. But there is still much uncertainty regarding the geological age of the rocks which have been affected by it. There can be no doubt that large masses of the old gneiss, torn up from below, have been thrust bodily westward for many miles, and are now seen with their dykes and pegmatites resting on the Durness limestones and quartzites. It is equally certain that in other districts huge slices of the Torridon sandstones have been similarly treated. But where all trace of original structure has disappeared, we have, as yet, no means of definitely determining from what formation the present eastern schists have been produced. The ordinary gneissose and quartzose flagstones do not appear to me to be such rocks as could ever be manufactured by any chemical or mechanical process out of the average type of Lewisian gneiss. I have long held the belief that they were originally sediments, but whether they represent altered Torridon Sandstone, or some clastic formations which may have followed the

Durness limestones, but which have been everywher entirely metamorphosed, remains for future discovery. I present purpose, it is sufficient to observe that, in the mea as we can not be sure of the origin of most of the rocks, between the West Coast and the line of the Great Gle been subjected to a gigantic post-Cambrian regional me phism, it seems safest to exclude them from an enumera the pre-Cambrian rocks of Britain.

Dalradian. East of the line of Great Glen, which c Scottish Highlands in two, another group of crystalline sc rocks is largely developed. It consists mainly of wha undoubtedly originally sedimentary deposits, though th now found in the form of quartzites, phyllites, graphitic mica-schists, marbles, and various other foliated masses. them are associated numerous eruptive rocks, both ac basic, sometimes still massive and easily recognizable as sive, sometimes more or less distinctly foliated and passi different gneisses, hornblende-schists, chloritic-schist Though it is not always possible in such a series of metan rocks to be certain of any real chronological order of suc those of the Highland tracts have now been mapped in det so wide an area, that we are probably justified in believi a definite sequence can be established among them. masses must be many thousand feet thick. Their suc and association of materials are so unlike those of any known older Palæozoic rocks of Britain, that they can ha the metamorphosed equivalents of any strata which recognized in an unaltered condition in these islands. traces of annelid casts have been found in the quartzi otherwise the whole series has remained entirely ba organic remains.

What then is the age of this important series? I mu fess that in the meantime I can give no satisfactory an this question. I have proposed, for the sake of distinct convenient reference, to call these rocks "Dalradian." I son supposed them to be a continuation of his Durness qu

limestones, and "younger gneiss." His belief may still prove to be in some measure well founded. But at present we have no means of deciding whether the quartzites and limestones of the Central Highlands are the more altered equivalents of the undoubtedly Cambrian strata of the north-west. It is possible that in the vast mass of metamorphosed rocks constituting the wide stretch of country from the northern headlands of Aberdeen to the south-western promontories of Argyllshire, there may be portions of the old Lewisian gneiss, tracts of highly altered Torridon sandstone, belts of true counterparts of the Cambrian quartzites and limestones of Durness, and, what should not be forgotten, considerable portions of some later sedimentary series which may have followed these limestones, but which, by the great dislocations already referred to, have disappeared from the north-west of Scotland. We are gradually learning more of these rocks, as the detailed mapping of them by the Geological Survey advances, and when the ground on either side of the Great Glen is surveyed, it may be possible to speak with more certainty regarding their true geological relations.

A glance at a geological map of the British Isles will show that the metamorphic rocks of the south-western Highlands of Scotland are prolonged into the north of Ireland, where they spread over a region many hundred square miles in extent. They retain there the same general character and present the same difficult problems as to their true stratigraphical relations. Quite recently, however, a new light seems to have arisen upon these Irish rocks. My colleagues on the Irish Branch of the Geological Survey have detected several detached areas of coarse gneisses, which in many respects resemble parts of the Lewisian gneiss of north-west Scotland. In some cases these areas lie amidst or close to "Dalradian" rocks, but with that obstinacy, which so tries the patience of the field-geologist, they have persistently refused to disclose their true original position with regard to these. Some fault, thrust-plane, tract of boulder-clay or stretch of bog is sure to intervene along the very junction-line where the desired sections might have been looked for.

There can be little doubt that a strong unconformability between them. A close examination of the ridge of old in Tyrone and Fermanagh showed me that though the basement-beds of this Dalradian series could not be seen on the coarse gneiss, the lithological character, and t arrangement of this series are only explicable on the supp of a complete discordance between it and the gneiss. A two groups of rock have never been found in close proxi Scotland, and as the determination of the true age Dalradian series is a question of such great stratigr importance in the general mapping of the United King requested Mr. A. McHenry, of the Geological Survey of I to continue the tracing of the mutual boundaries of t gneiss of the Ox Mountains and the Dalradian series in (Mayo. He informs me that he has found in that series glomerate full of blocks of the old gneiss, and resting locality apparently unconformably upon it. If this obse is confirmed it will finally set at rest the relative position coarse massive gneiss and some portion, at least, c Dalradian series. Of course there is no absolute proof tl coarse gneisses of Ireland are really the equivalents Lewisian masses which they so closely resemble. But t a strong presumption in favor of their identity.

In England and Wales many detached areas of roc been claimed as pre-Cambrian, and successive formation been classified among them. I have already dealt in pa this question, and without attempting here to review the inous literature of the subject, I will content myself with briefly what seems to me to have been established on evidence.

There can not, I think, be now any doubt that small tr gneiss, quite comparable in lithological character to porti the Lewisian rocks of the north-west of Scotland, rise surface in a few places in England and Wales. In the h Anglesey, for example, a tract of such rocks presents striking external or scenic resemblance to the charact

types of ground where the oldest gneiss forms the surface in Scotland and the west of Ireland. In the Malvern Hills another small knob of somewhat similar material is obviously far more ancient than the Cambrian rocks of that locality. There may possibly be still some further exposures of similar rocks in the south of England, as for instance in southern Cornwall. In Anglesey a series of schists, quartzites and limestones has been included by Mr. J. F. Blake with the coarse gneiss above referred to, and a thick higher group of slates in what he terms the "Monian" system. These schists, quartzites and limestones present a close resemblance to the Dalradian series of Scotland and Ireland, and the quartzites, like those of the Highlands, contain worm-burrows. The coarse gneiss, as I have said, may be compared in general character with parts of the Lewisian rocks, so that we seem to have here, as in Ireland, two groups of schistose rocks, and both of these must be much older than the unaltered Cambrian strata which lie above them.

Along the eastern borders of Wales, there is an interrupted ridge of igneous rocks which were originally supposed to have broken through the older Palæozoic formations, but which now, owing mainly to the labors of Dr. Callaway and Professor Lapworth, are shown to be older than the base of the Cambrian system. These rocks consist of spherulitic and perlitic felsites, with volcanic breccias and tuffs. They are undoubtedly older than the *Olenellus* zone. Though the evidence is not quite satisfactory, they may not impossibly lie at the base of a vast mass of sedimentary rocks forming the ridge of the Longmynd. In that case the whole of the Longmynd succession with the volcanic group at its base must be pre-Cambrian and lie unconformably below the *Olenellus* zone. Dr. Callaway has proposed the name "*Uriconian*" for this volcanic group, while the sedimentary series has been termed "*Longmyndian*." On the supposition that the unconformability is established, there would here be a vast mass of stratified and partly erupted material forming a pre-Cambrian formation. Whether in that case any portion of this English series is the equivalent of the Torridonian rocks of

Scotland remains to be determined. The north-western the Longmynd ridge is made of red sandstones and cong ates, which certainly resemble the Torridonian rocks of R Sutherland.

At the base of the Cambrian rocks in Wales, Dr. Hi described a marked volcanic series under the name of "Pet which he claims as pre-Cambrian, alleging that it is se from the Cambrian system by an unconformability, and a l conglomerates. I have carefully studied the evidence ground, and have come to the conclusion that there unconformability at the line in question, but that the o Cambrian strata graduate downwards into the volcanic gr can not be disjoined from it. I therefore regard the s "Pebidian" as merely marking the duration of a volcanic in early Cambrian time.

It will thus be seen that according to my view the un ably pre-Cambrian rocks of Britain consist of, first and the Lewisian gneiss; second, the Torridonian sandsto conglomerates. The Uriconian and Longmyndian for may prove to be in part or in whole equivalents of the donian. The Dalradian rocks have not yet had their determined. They may possibly mark a distinct pre-C series, but it seems quite as probable that they are metamorphic complex in which Archæan, Torridoni Cambrian, or even Lower Silurian rocks are included.

SIR ARCHIBALD GEIK
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ARE THERE TRACES OF GLACIAL MAN IN THE TRENTON GRAVELS?

IN a paper published in *Science*, Nov. 25. 1892, I undertook to study the evidence relating to paleolithic man in the eastern United States from a new point of view,—that furnished by certain recently acquired knowledge of the contents of quarries and shops where modern aboriginal flaked implements were made. It was shown that all rudely flaked forms could be sufficiently accounted for without the necessity of assuming a very rude state of culture, and that any people, paleolithic or neolithic, would in roughing out blades—the principal product of the flaking process—produce precisely these forms and in great numbers as refuse. It further appeared that the finding of these objects in sporadic cases in glacial gravels or in any formation whatsoever, could not be considered as proving or tending to establish the existence of a particular grade of stone-age culture for the region in which the formation occurs, since they may as readily pertain to a neolithic as to a paleolithic status. It was conclusively shown that no worked stone that can with reasonable safety be called an implement has been reported from the gravels, and that it is therefore clearly useless, not to say unscientific, to go on enlarging upon the evidence of an American paleolithic period and multiplying theoretic details of its culture.

I now propose to review briefly the question of the age of our so-called paleolithic implements, the questions of the *grade* of a given feature of culture and of the *age* or chronologic place of that culture being very properly treated separately, as they depend for their support upon distinct classes of evidence. During the past summer, 1892, certain important items of new evidence have been discovered bearing upon the question of the

occurrence or non-occurrence of rudely flaked stones or artificial objects whatsoever in the normal gravels of th ware Valley, and it therefore becomes necessary to e somewhat critically such of the published evidence as se be seriously affected by these recent observations.

It may be stated in beginning that no one disputes the age of the Trenton gravels. The question to be discu simply this,—is the evidence satisfactory that works of a been found in these gravels? Nothing else need be a answered. I do not take up this subject because I lo troversy; disputation is really most distasteful to me. It h that under the Bureau of Ethnology of the Smithsonian tion I have been assigned to the work of making a survey archeology of the Atlantic coast region in which large especially in states south of Mason and Dixon's line, re almost untouched by investigators, and two years hav consumed mainly in these southern areas. But there ar tions that refuse to be confined to definite geographic lim evidence secured in one section is sometimes found to l directly and forcibly upon problems pertaining primarily t sections that the student of these problems must perforce l a free lance, and unhesitatingly enter any province pr results of value, howsoever fully occupied it may be b investigators. One of the most interesting and importar tions growing out of the study of American archeology we have seen, arisen in the Delaware Valley, and the tur by some of my work in the south and west is such that I pass this question by without consideration. The nece taking up the subject of glacial man became more an apparent as the years passed on, and people continued tc me, "You must go to Trenton; we are not satisfied w present status of the question there; the evidence arr favor of the theory of a paleolithic gravel man needs examination."

The difficulty of taking up and re-examining evide which the record only remains, is, however, very great, s

most cases the evidence rests upon or consists of field observations, and these cannot be recalled or repeated, and there is absolutely no means of testing directly the value of what is recorded. One may seek either to verify or to discredit the promulgated theories, but years of search may fail to produce a single new item of evidence bearing decisively upon the subject. It is possible that at one period numerous finds of implements should be reported from certain portions of the gravels, and that afterwards the whole remaining body of these formations should be worked over and searched without securing a trace of art; yet this latter evidence, being negative, need not necessarily be considered sufficient to overturn the original positive evidence if that happens to be of a high class. There is not the least doubt, however, that positive evidence may be so impaired by various defects and inconsistencies, that, unsupported by renewed and well verified observations, it will finally yield to the negative forces; and if the theories of a gravel man in the eastern United States, howsoever fortified by accumulated observations, are not really properly supported in every way, they are bound in time to fall to the ground. All I can reasonably hope to do now is to have the evidence relating to glacial man placed on trial, and so fully examined and cross-examined that those who accept gravel man need not longer do so blindly without knowing that there are two sides to the question, and those who do not accept him may know something of the reasons for the belief that is in them.

The evidence employed to prove the presence of a race of men in the Delaware Valley in glacial times is confined almost wholly to the alleged discovery of rude implements in the glacial gravels. Practically all the evidence has been collected by Dr. C. C. Abbott, and upon his skill as an observer, his faithfulness as a recorder, his correctness of judgment and his integrity of character, the whole matter stands. Many visitors, men of high repute in archeology and geology, have visited the site, but the observations made on such occasions appear not to have been of a nature to be of great value in evidence, the finds being doubt-

ful works of art or not having properly established relationsl with the gravels in place. In the discussion of gravel mar eastern America a wide range of objects and phenomena been considered, but the real evidence, upon which the theor an ancient race and a peculiar culture must depend, is furnishe(a hundred pieces—more or less—of rudely flaked stones sai have come from the gravels in place. And now what can said with reference to this series of flaked stones further t that they are reported by the collector to have been found in gravels at definite stated depths? I have elsewhere shown they are not demonstrably implements in any case, that they identical in every respect with the quarry-shop rejects of American Indian, that they do not closely resemble any on the well established types of European paleolithic impleme and that they are not a sufficient index of a particular stag culture. I shall now present such reasons as there may be foi belief, held by many, that they were not really found in undisturbed glacial gravels.

It is generally understood that the earliest reported gr finds of importance were made on the banks of Assanpink c within the city limits of Trenton, where the gravels to a th ness of twenty feet or more were exposed in a railway cutt Later the river bluff near the lower end of the city, where gravels were exposed to a depth of from twenty-five to forty yielded large numbers. These two sites, so far as I can le furnished at least three-fourths of the finds in place. O specimens were found singly in slight natural exposures, an excavations for cellars, sewers, etc., at various points within city limits.

The river bluff was for a considerable period the fav hunting ground of the searchers for rudely flaked stones, many specimens were collected. The gravels were expose(a steep, nearly straight bank, several hundred yards in len the base of which was washed by the river. There can be question that Dr. Abbott and others have found shaped ob of various classes upon and in the face of this river bluff,

the visitor to-day, although the bluff is now buried almost completely under city refuse, will hardly fail to find some rudely flaked form in the deeper gullies or upon the narrow river bank or beach at the base. Dr. Abbott explicitly states[1] that he obtained certain of these specimens from the gravel outcrops, and that they were not in talus formations, but in undisturbed deposits. How then is it possible to do otherwise than accept these statements as satisfactory and final?

Very recently, however, fortunate circumstances have brought the evidence furnished by this site again within our

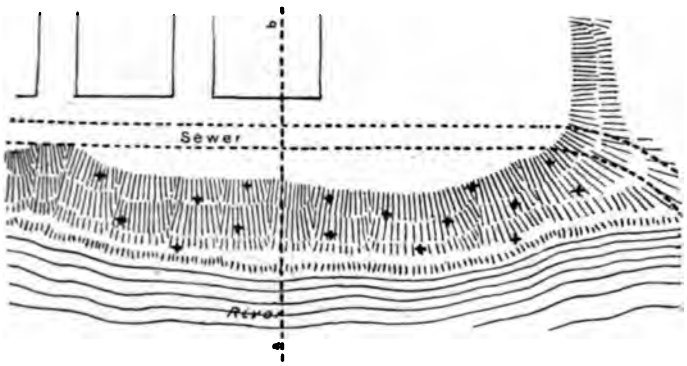

FIG. 1. Sketch map of the Trenton bluff, showing the relation of the sewer trench to the "implement" yielding slope. . . . a-b section line, FIG. 2.

reach, thus enabling us to re-open the discussion under favorable conditions. What I had for some time desired to do in this case was, what I had already done at Piny Branch, D. C., and at Little Falls, Minn., to open a trench into the face of the bluff, and thus secure evidence for or against the theory of a gravel man. This measure was, however, rendered impracticable by the occupation of the bluff margin by a city street; but it happened last summer that the city authorities, desiring to improve the sanitary condition of the city, decided to open a great sewer through this very bluff to get a lower outlet to the river. A trench twelve feet wide and some thirty feet deep, the full depth

[1] Abbott, C. C. Primitive Industry, pp. 493-510.

of the exposed gravels, was carried along the bluff just in its margin, opening out into the river at the point wh bluff turns toward the north-east. It was a trenching mor plete and more satisfactory than any of which I ha dreamed. At no point for the entire length of the bluff excavation depart more than forty feet from the line of t race face — from the upper margin of the slope upon whic plentiful evidence of a supposed gravel man had been ob The accompanying map and section, Figs. 1 and 2, will i

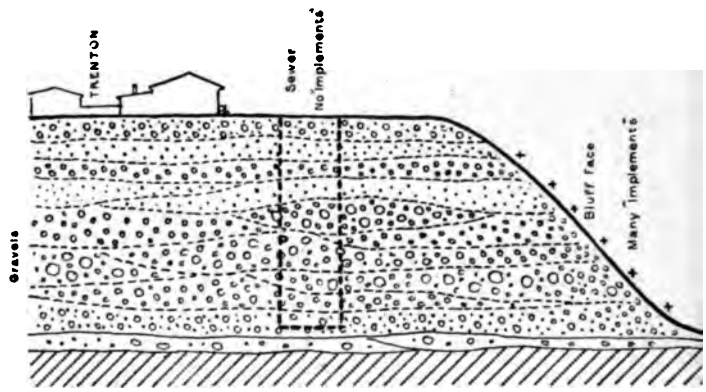

FIG. 2. Sections made by the river and by the sewer, the former yield "implements," the latter yielding none.

the location of the trench, and show the exact relations natural and artificial exposures of the gravels.

I made several visits to the place, descended frequent the great cut and examined the gravels and their conten the utmost care, but without securing a trace of art. Re ing the vital importance of utilizing to the fullest exte opportunity of testing the art-bearing nature of the gra this point, I resolved to undertake a systematic study subject. Summoning my assistant, Mr. William Dir from his field of operations in the South, I had him upwards of a month at the great trench, faithfully watch gravels as they were exposed. Mr. Dinwiddie had three years under my personal direction, and had helpe

upwards of twenty trenches through similar gravel deposits, and was therefore well qualified for the work. Prof. W. J. McGee, Prof. R. D. Salisbury, Dr. Stewart Culin and Dr. Abbott also visited the place one or more times each. Relics of art were found upon the surface and in such portions of the talus as happened to be exposed, but nothing whatever was found in the gravels in place, and the search was closed when it became fully apparent that the case was hopeless.

It may be claimed that the conditions under which gravels are exposed in trenching as it progresses, are not as favorable for the collection of enclosed relics as where exposed by natural processes of weathering. This is true in a certain measure, as specimens may be obscured by the damp clinging sand which forms the matrix of the gravels. This, however, would interfere but little with the discovery of large flaked stones, such as we were led to expect in this place, and this slight disadvantage in detecting shaped pieces in fresh exposures is more than overbalanced by the treachery of weathered surfaces which often give to intrusive objects the appearance of original inclusion. The opportunity for studying the gravels in all their phases of bedding, composition and contents, was really excellent, and no one could watch the constantly renewed exposures hour after hour for a month without forming a most decided notion as to the implement bearing qualities of the formation. Not the trace of a flaked stone, or of a flake or artificial fragment of any kind was found, and we closed the work with the firm conviction that the gravels exposed by this trench were absolutely barren of art. But Dr. Abbott claims to have found numerous implements in the bluff face a few feet away and in the same gravels. If this is true, the conditions of glacial occupation of this site must have been indeed remarkable. It is implied that during the whole period occupied by the melting of the ice sheet within the drainage of the Delaware valley the hypothetical rude race lived on a particular line or zone afterwards exposed by the river to the depth of 30 feet, leaving his strange "tools" there by the hundreds, while another line or zone, not more than forty feet away

at most, exposed to the same depth by an artificial trencl so avoided by him that it does not furnish the least mei of his presence. One vertical slice of the gravels twelv thick does not yield even a broken stone, while another sli probably one-half as thick, cut obliquely through the g near by, has furnished subject-matter for numerous bool substantiation for a brace of theories. That no natura of demarcation between the two section lines is possil shown by the fact that the formations are continuous, an the deposits indicate a constant shifting of lines and ar accumulation; thus it was impossible for any race to dwe

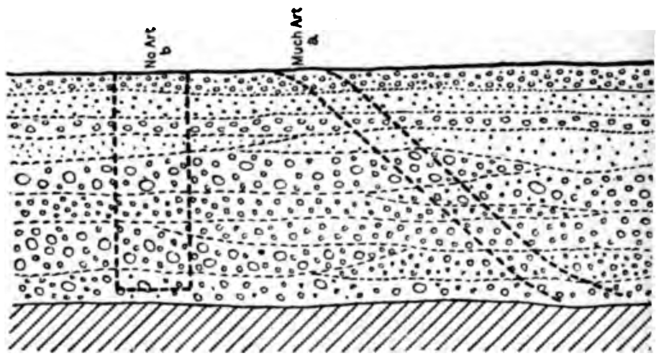

FIG. 3. *a*, Reputed "implement" producing zone of the river front. *b*, I zone of sewer.

tinuously upon any spot, line or plane. This is well showr section, Fig. 3, which gives the relations of the art-produci tion of Dr. Abbott to the non-art-producing section of the The gravels were laid down entirely irrespective of subs cutting, natural or artificial; yet we are expected to belie a so-called gravel man could have resorted for a thousan to the space *a*, leaving his half shaped or incipient tool stages of the gravel building from base to top, failing enti visit a neighboring space *b*, or to leave there a single f reward the most faithful search. It is much easier to that one man should err than that a guileless race shoul conspire with a heartless nature to accomplish such extrao

results. The easier explanation of the whole matter is that the objects found by Dr. Abbott were not really in the gravels, but that they are Indian shop-refuse settled into the old talus deposits of the bluff, and that his eager eyes, blinded by a prevailing belief in a paleolithic man for all the world alike, failed to observe with their wonted keenness and power.

But this case does not stand alone. The first discoveries of supposed gravel implements are said to have been made when the Pennsylvania Railway opened a road bed through the creek terrace on the site of the present station. At first numerous specimens of rudely flaked stones were reported, and the locality became widely known to archeologists, but the implement bearing portions of the gravels—and this is a most significant fact—were limited in extent, and the deposit was soon completely removed, the horizontal extension containing nothing. At present there are excellent exposures of the full thickness of the gravels at this point, but the most diligent search is vain, the only result of days of examination being a deep conviction that these gravels are and always were wholly barren of art.

It thus appears that here as well as upon the river front, the works of art were confined to local deposits, limited horizontally but not vertically, and a strong presumption is created that the finds were confined to redistributed gravels settled upon the terrace face in the form of talus. Dr. Abbott states that "at that point where I gathered the majority of specimens there is a want of stratification."[1] It is well known that such rearranged deposits are often difficult to distinguish from the original gravels. In trenching an implement producing terrace at Washington—where the conditions were probably quite similar to those at the Trenton railroad station—I passed through eighty feet of redistributed talus gravels before encountering the gravels in place, and so deceptively were portions of these deposits reset that experts in gravel phenomena were unable to decide whether they were or were not portions of the original formation

[1] Abbott, C. C. 10th Annual Report of the Peabody Museum, p. 41.

(cretaceous). The question was finally settled by the disco\ of artificially shaped stones in and beneath the deposits.

Again, an implement bearing deposit of gravel was rece discovered by the late Miss F. E. Babbitt at Little F Minnesota, and sufficient (a very little) digging was don satisfy the discoverer, and all paleolithic archeologists as v that the objects were really imbedded in the glacial gravels. the summer of 1892 I visited the place and carried a tre twenty feet horizontally into the terrace face on the "implen bed" level before encountering the gravels in place. The t deposits were several feet thick, and were of such a nature their true character could not be determined without careful extensive trenching. The whole talus deposit was here stocked with Indian quartz quarry-shop rejects, which wer usual of paleolithic types, and it was but natural that I Babbitt's conclusions, although based as they necessarily v upon inexpert observations, backed by such well known "typ of "implements" should be unhesitatingly accepted by believ

The occurrence of these telling examples of the decep appearance of re-set gravels would seem to justify and em size the conviction created by a critical examination of the leading so-called paleolithic sites at Trenton, that Dr. Abb notwithstanding his asseverations to the contrary, has b deceived. Very strong support, it seems to me, is given to conclusion by the recently published opinion of the late Dr. Carvill Lewis, a glacialist familiar with the Trenton region, with the work of Dr. Abbott at the period of his paleoli castle building. Dr. Lewis is reported to have maintai before an open meeting of the Academy of Science in Phila phia "that what Dr. Abbott believed to be undisturbed la (of gravel) were those of an ancient talus."[1] This rem may refer to both the main sites—the one at the railr station and the other at the river front—or possibly c to the former. I have also heard it stated that that emir scholar, Dr. Leidy, who must have had ample opportunities

[1]Brinton, D. G., Science, Oct. 28, p. 249.

forming correct opinions upon the subject, held pretty much the same views of Dr. Abbott's finds.

To make the above criticism entirely clear, a few words of explanation of talus phenomena may be added. As a river cuts its channel deeper and deeper into deposits of gravel a section is gradually exposed, but the gravels break down readily under

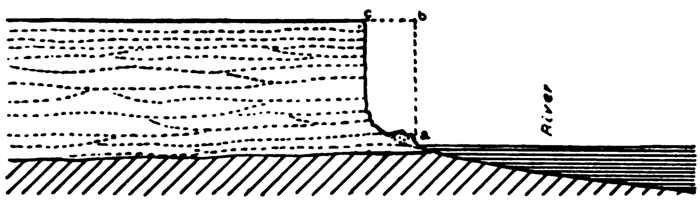

FIG. 4. A freshly formed gravel bluff.

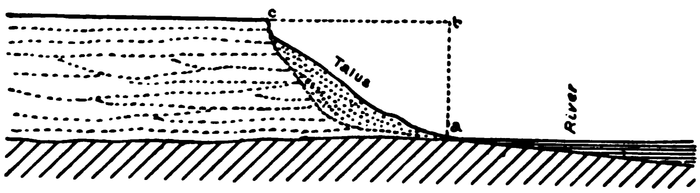

FIG. 5. Early stage of talus formation.

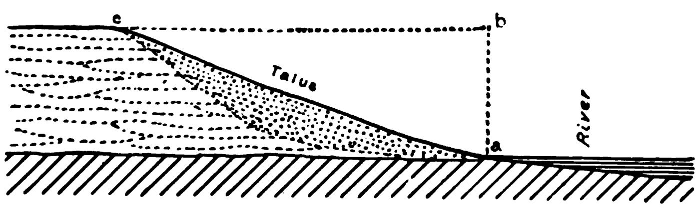

FIG. 6. An ancient talus.

atmospheric influences and the exposed face does not retain a high angle. The upper part crumbles and descends toward the base, there to rest against the slope or to be carried away by the stream. A supposititious case will be convenient for illustration. A gravel terrace twenty feet in height is encroached upon by the

river at high water and undermined, and the face break: vertically, leaving an exposure as illustrated in Fig. 4. In short time the upper portions become loosened and fall giving a steep slope as seen in Fig. 5. The process g with gradually decreasing rapidity, and if the river do again encroach seriously, a practically stable slope is re as shown in Fig. 6. Such a talus may be hundreds o thousands of years old, but there is rarely any means of mining its exact age. If the gravels are homogeneous i acter, the talus will simulate their normal condition so com that the distinction cannot be made out in ordinary gullie unsystematic digging. If the gravels contain varied str talus will be composite, and will be more readily disting from at least portions of the material in place.

Now it is important to observe what may be the poss contents of such a talus as that shown in Fig. 6. It m tain all objects of art originally included in that portion gravels represented by *a*, *b*, *c*, together with all articles th pened to be upon the surface *b*, *c*, beside such objects have accumulated from dwelling or shop work upon i surface, after the slope became sufficiently reduced to b pied for these purposes. A talus is therefore liable to c and in the utmost confusion, relics of all periods of occu supposing always that there were such periods, from the ning of the formation of the gravel deposits down to the moment. As a rule such a talus, if art-containing, will large percentage of shop and quarry-shop refuse, for the that the exposed gravels, and the banks and beds of riv ting them, furnish, as a rule, a good deal of the raw r utilized by workers in stone, and the shops in which th was done are usually located upon the slopes and outer r of the terraces. Although there is the possibility of ve siderable age for these talus deposits, it is unlikely th of them date back as far as the close of the glacial epoc all near it, for rivers change back and forth constantly. mining first one bank and then the other, so that a ve

percentage of our talus deposits have been formed well within the historic period.

At Trenton the constantly exposed gravel banks afforded considerable argillite in bowlders, fragments and heavy masses, as well as some other flakable stones of inferior quality little used, and it is inevitable that the Indian who dwelt upon the shores of the river should have sought the workable pieces along the bluff, leaving the refuse everywhere; and it is a necessary consequence that the terrace margin, the bluff face, and the talus deposits, places little fitted for habitation, should for long distances contain no trace of any art shapes save such as pertain to manufacture. Thus are fully and satisfactorily accounted for all the turtle backs and other rude forms that our paleolith hunters have been so assiduously gathering. Nothing can be more fully apparent than that no other race than the Indian in his historic character and condition need be conjured up to reasonably account for every phase and every article of the recovered art. Mistaken interpretations of the nature of shop rejects, and the common association of these objects with redistributed gravels, are probably accountable for the many misconceptions that have arisen. Talus deposits form exceedingly treacherous records for the would-be chronologist. They are the reef upon which more than one paleolithic adventurer has been wrecked.

Relics of art attributed to gravel man have been collected, so far as I can gather from museum labels and from incidental references in various publications, from a number of sites aside from the two already referred to. These are scattered over the city, and the finds were made mostly in exposures of the gravels that remained visible for a short time only, as in street and cellar excavations and well pits. These reported finds can never be brought within the range of re-examination, and the searcher after unimpeachable testimony must content himself with placing them in the doubtful column on general principles. Urban districts are so subject to disturbance through cutting down of hills, filling in of depressions, grading of streets, digging of

foundations, cellars, sewers, wells and graves that no man from a limited exposure such as those producing the repc tools necessarily were, speak with certainty of the undistu nature of the deposits penetrated. It is doubtful if any oı justified in publishing such observations at all without se: query. Such testimony is liable to fall of its own inherent w ness, being absolutely valueless if unsupported by colla evidence of real weight. It can only be made perman available to science by the discovery of something unusu: unique with which to couple it, something decidedly un-Ir in character or type, as for example the two skulls now in Peabody Museum. These objects and the antler knife-hɛ exhibited with them may be alluded to as the only finds s made at Trenton, having of themselves the least potentialit proof and these skulls and this knife-handle must ye subjected to the rigid examination made necessary by importance of the conclusions to be based upon them.

Something may now be said concerning the art remains which this discussion hinges, and upon which conclusions o greatest importance to anthropology are supposed to de Let us pass over all that has been said with regard to manner of occurrence and association with the gravels anc them simply what story they tell of themselves. Does story, so far as we are able clearly to read it, speak of a antiquity and a peculiar culture, or does it hint rather at weaknesses in the position taken by the advocates of these i We shall see. The history of the utilization of rudely f stones in the attempt to establish a gravel man in Americ never been written, but as read between the lines of paleo literature, it runs about as follows: The theory of a very and ancient people, having a unique culture and certain pe art limitations, was developed in Europe many years ago manner well known and often rehearsed. This people associated with the ice age in Europe, and this epoch, wi moraines and till and sedimented gravels, was found to been repeated in America. It was the most natural

possible that these discoveries should carry with them the suggestion that man may have existed here as in Europe during that epoch, and that his culture was of closely corresponding grade. These were legitimate inferences and warranted the instituting of careful researches, but it was a dangerous suggestion to put into the minds of enthusiastic novices with fertile brains and ready pens. The idea was hardly transplanted to American soil before finds began to be made. The so-called "types" of European paleoliths suggested the lines upon which finds here should be made, and everything in the way of flaked stones connected directly or indirectly with the glacial gravels which had not yet been fully credited to and absorbed by the inconvenient Indian, was seized upon as representing the ancient time and its hypothetic people and culture. In the early days of the investigation the various rude forms of flaked stones, resulting from failures in manufacture, had not been studied, and were shrouded in convenient mystery, and they thus became the foundation of the new archeologic dynasty in America, the dynasty of the turtle-back. Dr. Abbott states in his first work[1] that these rude "implements" are not especially characteristic of any one locality, but seem to be scattered uniformly over the state. Specimens of every type, he says, are "found upon the surface, and are plowed up every spring and autumn; but this in no way militates against the opinion that these ruder forms are far older than the well-chipped jasper and beautifully-polished porphyry stone-work."[2] At that stage of the investigation it was not at all necessary that a specimen should come from the gravels in place or from any given depth, since the "type" was supposed to be easily recognized and was a sufficient means of settling the question of age.

Rude "implements" were called for and they were found. The only requirements were that they should not be of well-known Indian types, that they should be rude and have some sort of resemblance to what were known as paleolithic implements

[1] Abbott, C. C. The Stone Age in N. J., Sm. Rep. 1875, p. 247.
[2] Ibid, p. 252.

abroad. Since most of these so-called gravel implemei Europe are also doubtless the rejects of manufacture resemb were readily found. The early attempts to utilize these r in support of the theory, and make them masquerade cred as "implements" with specialized features and self-e adaptation to definite ice-age uses, now appear decidedly ing. Gradually, however, the lines have been drawn upo early license, and it is to-day well understood by all c students, that since the rude forms are so often repeat modern neolithic refuse, the only reliable test of a "implement" is its occurrence in the gravels in place. particular "implement," said to have been obtained fro gravels, is of "paleolithic type," does not in the least strer its claims to being a *bona fide* gravel implement; nor dc easy assignment to a "type" give any additional value collector's claim that the gravels said to contain it are impl bearing. The very names, "rude implement," "pale implement," etc., carry with them a certain amount of terious suggestion; one thinks of unique, significant shape of strange, archaic uses. At their mere mention, the gre sheet looms up with startling realism, and the reindeer ar mighty mammoth appear upon the scene. The reader paleolithic literature is led to feel that these antiquated c carry volumes of history in their worn and weather-beaten but this is all the figment of fertile brains. These objects without exception the appearance of the most commo every-day rejects of manufacture without specializatic without hidden meaning. They tell of themselves no whatsoever, save that of the oft-repeated failure of the iginal blade maker in his struggle with refractory stones. will be shown with greater clearness farther on.

But the scheme does not end with the repetition of a pean state of affairs. Our gravel archeologists have no content to adopt that feature of the foreign scheme utterly destroys the paleolithic race before a higher cul brought upon the scene. It was thought to improve up

borrowed plan by allowing for a gradual development upward from the paleolithic stage, represented exclusively by a class of meaningless bits of flaked stone, through a period less rude, characterized by productions so far advanced as to be assigned to a definite use. These latter productions consist mainly of rather large and often rude blades, sometimes plain, but generally notched or modified at the broader end as if to be set in a handle, or attached to a spear or arrow shaft. These were assigned to post-glacial times in such a way as to bridge or partly bridge the great space between the glacial epoch and the present. They were separated arbitrarily from the body of the collections of the region, and referred to as probably the work of an Eskimo race. This arrangement produced a pleasing symmetry and completeness, and brought the history of man down to the beginning of the Indian epoch, which is represented by all of those forms of art with which the red man is historically associated.

Three principal periods are thus thought to be represented by the finds at Trenton; and in the arrangement of the collections these grand divisions are illustrated by three great groups of relics, which are looked upon by the founders of the scheme as an epitome of native American art and culture. By others this grouping is looked upon as purely empirical, as an arbitrary separation of the normal art remains of the historic Indian, not suggested by anything in the nature or condition of the objects, nor in the manner of their discovery.

The "Eskimo" feature of the scheme requires a more detailed examination than can be given it here. It may be stated, however, that the separation of the so-called Eskimo spear points, or whatever they may be, from the great body of associated articles of flaked stone, appears to be a highly arbitrary proceeding. That they were extensively made by the Indians is proved by the occurrence of refuse resulting from their manufacture on modern shop sites, and that they were used by the Indian, is equally apparent from their common occurrence on modern dwelling sites. The exceptionally large size of the

argellite points is readily accounted for by the nature material. It was the only stone of the region well ada the manufacture of long blades or projectile points. quartz and flint have such minute cleavage that, save cases, small implements only could be made from them. peculiar manner of occurrence, described at so much lei Dr. Abbott,[1] has been given undue consideration and The phenomena observed may all be accounted for as a ı the vicissitudes of aboriginal life and occupation within few hundred years as fully and satisfactorily as by ; thousands of years backward into the unknown.

Whatsoever real support there may be for the "E theory, either in the published or the unpublished evider apparent that under the present system of solitary and i research, the scientific world will gain little that it ca without distrust and danger. Whatsoever may be the fi come—which outcome is bound to be the truth—it is cl there is little in the present evidence to warrant the tion of a "paleolithic" and an "Eskimo" period of a that of the Indian.

That the art remains of the Trenton region are esse unit, having no natural separation into time, culture c groups, is easily susceptible of demonstration. I have presented strong reasons for concluding that all the fin the Trenton sites are from the surface or from recent c and that all may reasonably be assigned to the Indian. has recently been made which furnishes full and deci dence upon this point. At Point Pleasant, on the D some twenty-five miles above Trenton, there are out argillite, and here have been discovered recently the sh upon which this stone was worked. There are two fea these shops to which the closest attention must be give first is that they are manifestly modern; they are sit the present flood plain of the Delaware, and but a few fe average water level, the glacial terrace here being some

[1] Abbott, C. C. Popular Science Monthly, Dec., 1889.

fifty feet in height. These shops, therefore, represent the most modern phases of aboriginal industry, and may have been occupied at the coming of William Penn. The second point is that every type of flaked argillite found in the Trenton region, associated with the gravels or otherwise, is found on this site. It was to a certain extent a quarry site, for the great masses of argillite brought down by the floods were here broken up and removed from the river banks or bed. It was a shop site, for here the articles, mainly blades, were roughed out, and it was also a dwelling place—a village site—where all the specialized forms of flaked stones made from the blades were prepared for use. Here are found great numbers of the rude failures, duplicating every feature of the mysterious "paleolith" with which our museums are stocked, and exhibiting the same masterly quitting at just the point "where no further shaping was possible."[1] Here we see the same boldly manipulated "cutting edge," the "flat bottom" and "high peak," and the same mysteriously weathered and disintegrated surfaces, so skillfully made, by a nice balancing of accidents,[2] to tell the story of chronologic sequence in deposition.

Beside the failures, we have here, as on other quarry shop sites, the evidence of more advanced work, the wide, thick, defective blades, and many of the long, thin blades broken at or near the finishing point. Here, too, just back of the roughing-out shops, are the dwelling sites from which many specialized forms are obtained. The "Eskimo" type is fully represented as well as the ordinary spear point, the arrow point, and the perforator of our Indian. There is not a type of flaked argillite known in the Delaware valley that may not be duplicated here on this modern Indian site, and this has been known by local archeologists for years. Why so little has been said about the matter is thus explained. Dr. Abbott, in 1890, discovering this site, and finding "typical paleolithic implements" (the ordinary ruder forms of rejects) among the refuse, was so entirely at a

[1] Abbott, C. C. Smithsonian Report, 1875, p. 248.
[2] Ibid. Primitive Industry, p. 487.

loss to explain the occurrence that he felt compelled to a "take up the examination of the gravel deposits of the valle the Delaware" with the hope of "finally solving the proble The true conditions would have been at once apparent to one not utterly blinded by the prevailing misconceptions.

The entire simplicity of the archeologic conditions ir Delaware valley may be further illustrated. Had William] paused in his arduous traffic with the tawny Delawares, glanced out with far-sighted eyes from beneath the pen branches of the great elm at Shackamaxon, he might beheld an uncouth savage laboriously fabricating rude ice tools, making the clumsy turtle-back, shaping the myste: paleolith, thus taking that first and most interesting theore step in human art and history. Had he looked again a moments later he might have beheld the same tawny indiv: deeply absorbed in the task of trimming a long rude spear] of "Eskimo" type from the refractory argillite. If he again paused when another handful of baubles had been ciously exchanged, he would have seen the familiar rec carefully finishing his arrow points and fitting them to shafts preparatory to a hunting and fishing cruise on the p Delaware. Thus in a brief space of time Penn might gleaned the story of the ages — the history of the turtle-l the long spear point and their allies — as in a single sheaf. the opportunity was wasted, and the heaps of flinty refuse upon the river bank by the workmen were the only recorc of the nature of the work of that day. Two hundred yea aboriginal misfortune and Quaker inattention and neglect resulted in so mixing up the simple evidence of a day's \ that it has taken twenty-five years to collect the scattered ments, to sift, separate and classify them, and to assign the theoretic places in a scheme of culture evolution that span: thousand years.

Yet is there really nothing in it all, in the theories

[1] Abbott, C. C. Annual Report of the Curator of the Museum of An Archeology, University of Pennsylvania. No. 1, p. 7.

observations, the collections and the books? Do I speak too positively in condemnation of the results of years of earnest investigation? Perhaps so, but the voluminous testimony is so overloaded with inaccuracies, the relics of unscientific method and misleading hypotheses, that every item must be sharply questioned; and the conclusions reached so far overstep the limits warranted by the evidence, that heroic measures alone can be effectual in determining their exact value. If, as many believe, vital errors have been embodied in the evidence presented by the advocates of the theory, it is impossible to state the case too strongly. Error once fully absorbed into the literature of science has many advantages over the tardy truth; it is strongly fortified and must be attacked and exposed without fear or favor. Truth involved with it cannot permanently suffer. If the twin theories of a gravel and a paleolithic man in eastern America are to be assailed as unsound or as not properly supported, it should be done now while the originators and upholders are alive and alert to sustain their positions or to yield to the advances of truth. I do not wish to wrongly characterize or to unduly minimize the evidence brought to bear in favor of these theories. I do intend, however, to assist the world so far as possible in securing an exact estimate of all that has been said and done, and all that is to be done.

In a previous article I have examined the evidence relating to paleolithic art in the eastern United States, and have indicated its utter inadequacy and unreliability. In this paper the testimony relating to the occurrence of gravel art, in the locality most fully relied upon by advocates of the theory, has been partially reviewed and subjected to the strong light of recent observations. It is found that the whole fabric, so imposing in books and museums, shrinks away surprisingly as it is approached. The evidence furnished by the bluff face and by the railway cutting, the two leading sites, is fatally weakened by the practical demonstration of the fact that the gravels proper are at these points barren of art remains. In endeavoring to naturalize an immigrant hypothesis, our gravel searchers, unac-

quainted with the true nature of the objects collected discussed, and little skilled in the observation of the p nomena by means of which all questions of age must be de mined, have undoubtedly made grievous mistakes and have misled an expectant and credulous public.

The articles themselves, the so-called gravel finds, w closely studied are found to tell their own story much r fully and accurately than it has heretofore been read by stud of archeology. This story is that the art of the Delaware va is to all intents and purposes a unit, that there is not unique or especially primitive or ancient and nothing un-In in it all. All forms are found on demonstrably recent site manufacture. The rude forms assigned by some to glacial t are all apparently "wasters" of Indian manufacture. The blades of "Eskimo" type are only the larger blades, knives spear points of the Indian, separated arbitrarily from the of the art-remains to subserve the ends of a theory, ce obscure phenomena of occurrence having been found to color to the proceeding. To place any part of this art, ruc elaborate, permanently in any other than the ordinary In category will take stronger proofs than have yet been devel in the region itself.

The question asked in the beginning, "Are there trac glacial man in the Trenton gravels?" if not answered decis in the negative, stands little chance, considering present dence, of being answered in the affirmative. In view of the that numerous observations of apparent value have been in other sections, there is yet sufficient reason for lettin query stand, and we may continue to cherish the hope that sibly by renewed effort and improved methods of investig something may yet be found in the Trenton gravels c demonstrative of the fascinating belief in a great antiquity fo human race in America.

The evidence upon which *paleolithic man* in America de is so intangible that, unsupported by supposed analogies European conditions and phenomena, and by the suggestic

an ideal scheme of culture progress, it would vanish in thin air; and if the theory of a *glacial man* can summon to its aid no better testimony than that furnished by the examples examined in this paper, the whole scheme, so elaborately mounted and so confidently proclaimed, is in imminent danger of early collapse.

W. H. Holmes.

GEOLOGY AS A PART OF A COLLEGE CURRICULUM.

THE demand for scientific studies as a part of the col
curriculum is felt by all those who have to do with the prov
of higher instruction for American youth. The reasons for
may be various, but a fundamental reason is found in the
dency among the American people in particular, and in this
in general, toward practicality in all things. Applied to ec
tion this practicality asks for a training which shall have a d
bearing upon the business of life to be followed immedi
after the training period is ended. It means a differentiati
subjects and specialization in methods to adjust the educ
to the different functions which the students taking it are pr
ing for. It calls for a professional education for those
expect to become lawyers, doctors, ministers, or teacher
technical education for those who are to engage in the ar
the mechanical or civil engineer, or of the architect. It r
not only in the establishment of colleges and univer
devoted to this kind of education, but it affects the me
of the high schools and academies, and is felt down to pri
schools, and on the other hand the older institutions fo
on a different plan are adapted to the popular demand b
addition to the regular studies of "electives," chosen not a
for their value or disciplinary studies, but because o
practical applicability of the information to be derived
them, to the business of the student.

Without discussing the relative merits of the two id
education, the chief contrast between them may be found
character of the results sought. The knowledge of thing
their uses is of chief importance in the practical educatior
knowlege of ideas and skill in their use is the aim of the
education. Geology is one of the sciences which most men

once classify as among the practical sciences. It deals with matters of practical importance to everybody. Coal, iron, the metals, silver, gold, tin, lead, building stone, sand, clay, petroleum, and natural gas, and all geological products are essential materials of modern civilization, and a knowledge of them and of their modes and places of occurrence is one of the requisites of an education, either from the practical or the liberal point of view. So too the dynamics of atmospheric and hydraulic erosion, the agency of rivers and oceans in destruction, removal and reconstruction of geological formations have their eminently practical bearings upon the various arts of engineering. While the practical value of geology is thus evident and undisputed, it is not on this account that its importance as a part of a college course of education is urged. As a practical study geology becomes the centre of a group of studies requiring years for mastery. Chemistry and physics are primarily essential to a full understanding of the most common of geological problems. And to use geological facts and phenomena, an acquaintance with the complex methods of engineering, civil and mechanical, which again call for a thorough mastery of mathematics, is necessary. Mineralogy and petrography, metallurgy and mining engineering have each reached a stage of development entitling them to the rank of separate sciences, but the practical training of the geologist should include them all. When we add the biological sciences connected with historical geology, paleontology, zoölogy and botany, with all the laboratory and field work required for their proper study, we have a group of affiliated branches of learning requiring four or five years of continuous study after the student has learned how to study. It is plain therefore that only a specialist, one who is willing to neglect other studies, or who has previously had a liberal training, can perfect himself on the practical side in the science of geology.

But irrespective of its practical uses, as a means of training and supplementary to the ordinary studies of a college curriculum, geology is one of the most useful of the sciences of obser-

vation. It is in providing that particular training to v President Eliot has recently called attention in the *Forum* (1892, Wherein Popular Education Has Failed), that ge can be used to such advantage. Speaking particularly o lower education, President Eliot says it is "the judgment reasoning powers" that particularly require attention. systematic development is to be attained in the four dire of "observing accurately, recording correctly, comp grouping and inferring justly, and expressing cogentl results of these mental operations." (p. 421.) The attair of these ends is one of the purposes of liberal education, wh it be in the primary school or in the university. And gec or any other science, is of value in a college course in prop to its fitness for the exercise and development of these fun of the student. Geology may be taught without regard to ends, and then it is valuable from the practical point of but when we examine it in respect of its availability as a d linary study we find it offering particular attractions.

Using the distinction between theory and practice, wh as old as Aristotle, geology in its theoretical aspect is more comprehended than is the theoretical aspect of most modern sciences. This arises first from the fact that the and phenomena are of a simple and grand nature, making i sible for the teacher to direct certain attention to the s facts under consideration. The water of the rivers, the m the road side, the rocks and sands on the shore are fa objects to all, and it is a simple matter to call attentic ordinary language to the specific facts regarding them, analyzed out, are to form the basis of exact ideas and sci definition and classification. Geology is the one science a the natural sciences which may begin with the common lan of the pupil, and by means of such language alone may bu ideas of precise phenomena in scientific terms. Physiog or physical geography surpasses geology proper in thi ticular, as the admirable work of Professor Davis is sh and on this account it is the best introduction to geology.

the very largeness and indefiniteness of the facts are in the way of the use of physical geography for the exercise of the finer and more exact functions of observation. The disciplinary value of classics and mathematics is to a considerable extent derived from this quality, the precision with which the words or figures kindle like ideas. So long as the object of the training is to teach the knowledge of ideas and how to use them, classics and mathematics are the simplest and purest means of developing a liberal education. The addition of sciences to the college course is not because of the usefulness of the knowledge of things thus to be gained, but because the language of the sciences is essential to call forth the observation and the exercise of the accompanying mental operations.

When it comes to dealing with the ideas associated with particular sense-observation, where form or motion can not be expressed in simple mathematical terms, language can not communicate a new idea or kindle it in another mind with precision. It is necessary by some means to recall or to present the object itself to the student. In the teaching of science this point is of great importance, and much of the unsatisfactoriness of science-teaching is doubtless due to failure to note it. No circumlocution of words can arouse in another or communicate to him the idea appropriate to a sensation he has never felt. The blind man whose eyes are opened sees men as trees walking.

In the use of science for elementary training (and the training is elementary until the student is capable of investigating and interpreting the facts and phenomena of a science directly) that science is the better which deals with objects which are simple, common and easily observed. Such is geology in some of its aspects. Every time the student walks in the country he sees the facts discussed in the text-book or by his teacher; and from attention to those with which he is already familiar he can be readily led to observe and give attention to others and to analyze those already in his mind by properly directed questions.

In the field of geology are found the ready means for the exercise and development of observation and thought. The

learner begins with ideas which every intelligent mind associ with the objects described or named, and by degrees the ma of his knowledge are increased, the relations of things grasped, and the content of his ideas associated with the l guage of his science is enlarged. In the process of learn the science he has been building up his stock of knowledge facts and phenomena, but, of more importance than that, he learned the method of observing and of scientific thinking. has had training in the methods of reducing the hard fact nature to the laws of thought and practice, he has seen method by which theoretical order is made out of the in minable confusion and complexity of natural things.

Beside this primary reason for the use of geology as a d plinary science-study, there is a second reason arising from symbolic nature of a large group of its facts. This aspec the science is best seen in the historical and stratigraphical p of geology, in which fossils are the chief data for study. interpretation of a fossil into a species of organism, havin definite place in the elaborate classification of the zoölogis as an indicator of the time and place and mode of formatio the strata in which it is buried, is, to be sure, a most intri and, at first thought it would seem, an unattractive process. no more so, I would say, than the interpretation of a seri Greek characters. The interpretation of the Greek reveal us the richest results of human thought and most perfect of human speech, and we find therefore in the analysis requ the most perfect discipline of the powers of speech and guage. The fossil too holds, ready to be revealed, the sto the history of the world and the laws of the evolution o organic life of the globe, and records an inexhaustible w of information regarding the laws of nature. But as an in ment of intellectual discipline its great merit lies in its sym nature. It is this symbolic character of the classical langu and of the mathematics which fits them to be universal m of liberal training. The symbolic nature of the fossil fits become the exponent of training in the pure science of na

The fossil is a mark which stands for something, and thus, in the nature of things, it asks for interpretation. As a symbol it stimulates minute and accurate observation, and kindles close and exhaustive thought; as a symbol it leaves us the ideas it has engendered after it is lost to memory as an observation. Thus the value of its study does not depend upon the retention in the memory of the facts brought before the mind, but in the training of the mental processes required in its interpretation. The study of this branch of geology exercises and develops all the faculties which are specially exercised in any scientific investigation.

Another aspect in which it is an ideal means for such training comes from the fact that it is equally valuable at every stage of progress of the student. When first examined it means nothing to him. He knows nothing of organism, of strata, of geological time. The fossil gains meaning only as he is able to put meaning into it. The student must ask questions, and as step by step he answers his questions by more minute and wider examination, the fossil holds a fuller interpretation. His studies lead him to investigation of the whole field of nature, the rocks, the formation of deposits, the action of the elements, the conditions of life, the forms of organism, their functions and habits, the laws of growth, their adaptation to environment, the changes of events in time, the efforts of association and struggle for life, the principles of evolution and development—the migration and origin and extinction of organisms on the globe. Nothing in nature is without interest to him. Further than this the amount of good he gains is not measured by the number of fossils he studies, but by the wideness of his research. A handful of fossils from some one fossiliferous ledge may be the text for a year's study, and the methods acquired in the study may be the nucleus of a life's work. In this department of geology the possibilities for new discoveries, new developments of science are almost endless. As a single author thoroughly read develops a wealth of knowledge of the laws of language and thought, so geology may be

studied by the use of a limited set of its phenomena and bec
the introduction to the exhaustive study of natural science.

Another advantage attaching to geology as a science-st for the college curriculum, arises from the fact that it may pursued deeply without the elaborate aid to the senses requ in other sciences for making minute record or measuremen facts or phenomena. As in language and mathematics, essential to acquire a familiarity with the grammar, the dict ary and the symbols, formulas and rules of their usage be the finer training in the use of thought begins, so the vocabu and the definitions of a science must be acquired before n use can be made of the higher discipline to be derived scientific study. In language study this higher training cc from practice in making the minute analysis, in detecting fine shades of meaning expressed in the literature itself. S is important in selecting a science to be used as a discipli study that the facts and laws of nature with which it is conce should be capable of clear and precise definition, and, more that it should furnish a field for the study of the minute intricate relationship existing between the different facts w are to be attained by personal inspection of the objects t selves. In most of the sciences this deeper exercise of scie thought requires for its successful pursuit artificial aids tc common senses of observation. Chemistry must have its fied acids and reagents, test tubes, and delicate scales measurement of weight and volume. Mineralogy must hav chemical analyses, or optical measurements so fine that m scopes of highest power are essential tools for the investig Physics must have the most delicate measurements of and space and weight. Botany, for the earlier stages of s is fully equal to geology in these respects, but its scope is less general. Zoölogy requires dissections calling for sk manipulation, and in other respects is ill adapted to ge classes. But precision in the intellectual processes of obs tion and reasoning can be cultivated in the use of geol facts to their highest and widest perfection, with scarcel

aids to the normal faculties of observation. A couple of hammers, a pocket lens, a chisel and a few pointed steel tools for revealing fossils, a tape line, compass and clinometer are the few equipments that will enable the geologist to carry his investigations to almost any degree of thoroughness.

What has already been said applies to the study of the pure science of geology either in the field or in the laboratory. There is still another use to which this, as other sciences, may be put in disciplining the college student in directions not provided for by literary or mathematical studies,—the study of man as an investigator. In the pursuit of the study of geology, the first instruction must be received in didactic form, but after the text-book and lecture stage is passed, or while it is under way consultation of the literature of the sciences is appropriate. In the use of scientific literature the critical judgment is brought under training, and the varying interpretations of well known phenomena by expert scientists suggest the prominent part which the notions already in the mind play in the interpretation of the external facts observed. The experienced geologist will recall many cases of honest report of impossible facts by men who are unable to distinguish between what they saw and the false interpretations they made of these observations. One man will report that a live toad jumped out of the middle of a solid piece of coal, when it was heated in the stove; another will swear that he saw a fossil shark's tooth taken out of a ledge of Trenton limestone. It is evident that our memory of observation is not the revival of the object producing the sensation, but of the idea we framed of the sensation at the time. The study of original descriptions of objects of nature reveals the fact that the describer uses the ideas he already has in his mind as he does the standard foot-rule in his hand for measuring that which he describes, and it is by the study of scientific literature and the comparison of views of many scientists that this highest discipline of the observational faculties is attained—the power to determine the personal equation of error for the observer, and thus see through his descriptions a truer represen-

tation of the facts than the observer himself saw. Geolog literature is admirably adapted for this higher discipline, an no field of science (I think not in astronomy itself), has w and more comprehensive thought been applied than in geol While other branches of science have been developed become more narrow and special in their treatment of the 1 concerned, geology still stands as the most comprehensiv all the sciences of nature.

H. S. WILLIAM

YALE COLLEGE, November 30, 1892.

THE NATURE OF THE ENGLACIAL DRIFT OF THE MISSISSIPPI BASIN.

It is of some importance, both to the practical work of the field and the theoretical deductions of the study, to determine the nature and amount of the drift that was carried forward in the body of the ancient continental glaciers, and brought out on their terminal slopes and at length deposited at their frontal edges, and to distinguish it from that which was pushed or dragged or rolled along at the bottom of the ice.[1] It may be helpful to indulge in a speculative discussion at the outset to prepare the way for the specific evidence and the inferences to which it leads.

Whenever a prominence of rock is overridden and enveloped by a glacier of the free-moving continental type, one of two things takes place; either that part of the ice which passes over the summit of the prominence flows down its lee slope, carrying whatever debris it dislodges down to the rear base, and thence onward along the bottom of the ice, or else the currents which pass on either side of the prominence close in behind it before the corresponding current which passes over the summit reaches the point of their junction, in which case the summit current is forced to pass off more nearly horizontally into the body of the ice, carrying with it whatsoever debris it has dislodged from the summit of the prominence and embodied within its base. The law of the phenomena appears to be that whenever the height of the prominence is less than one-half the base, measured transversely to the movement of the ice, the summit current will follow down the lee slope; but whenever the height of the promi-

[1] Debris, which may be imbedded in the basal layer of the ice during some part of its transportation, but which is brought down to the bottom and subjected to basal action in the latter part of its course, and ultimately becomes a part of the basal deposit, is not here included in the englacial drift.

nence is more than one-half the transverse base, the lat currents will close in on the lee, and the summit current will off into the body of the ice. This simple law is, however, sul to very considerable modifications from several different sou which may be grouped under (1) differences in the fri arising from basal contact, and (2) differences of internal tion and mobility. The lateral currents will expose more su to the sides and base of the hill and the adjoining plain will be more subject to conflicting currents, while, on the hand, being deeper currents, they will presumably be more fl These and other qualifying conditions will go far to vitiat application of the law, but its statement may have some as representing a general conception of the phenomena. \ the height of the prominence becomes great relative to the thickness of the ice, the fluency of the summit current m much reduced relative to that of the central parts of the l currents. When the prominence reaches the surface, b dislodged from it are borne away on the surface of the gl and constitute superglacial drift. Blocks dislodged from the summit, but below the surface of the ice, are presur carried onward in the upper zone of the glacier; while blocks detached at various but sufficient heights on the s the prominence are doubtless borne around into the lee an ried forward in the same vertical plane as the summit strea that there comes to be a vertical zone set with boulders m on from the lee side of the nunatak.

Lofty ledges or plateaus, with vertical or undercut furnish similar means for the lodgment of debris withi body of the ice.

In these and doubtless in other ways it appears that came to be lodged directly within the body of the Pleis glaciers at some considerable distances above their bases, derived from rock prominences that rose with sufficient ness above the general surface of the country over which t passed. The lodgment of debris on the lateral borders c ciers is neglected here because it has little or no applicab

the phenomena of the upper Mississippi basin. It is also doubtful whether any prominences protruded through the ice except near the thin edge, when advancing and retreating, and these are too inconsiderable to merit attention.

It is obvious, upon consideration, that blocks detached from summits or from the sharp angles of out-jutting ledges or plateaus might suffer some glacial abrasion in the process of their dislodgment and transposition along the crest or projecting angle, but that in general such abrasion would be small, and, in most cases, nearly or quite absent. The debris so incorporated in the body of the ice would be, for the most part, angular, and, as it was brought forward in the ice, it would probably suffer very little abrasion. If it continued to move forward in the plane in which it started, descending only so much as the bottom wastage of the ice required, it would be brought out to the terminal slope of the ice sheet by virtue of the melting away of the ice above, and thence it would be carried on down the terminal slope as superglacial debris, and dropped at the frontal edge. If this be the true and full history, there would be no commingling of this englacial matter with the subglacial debris. It is evident that the englacial matter brought forward from the crest of one prominence would be intermingled with that brought forward from other prominences lying in a line with it, or lying so near it that the lateral spreading of the debris would lead to commingling. It is also clear that variations in the direction of currents would tend to the same result, so that englacial matter from different prominences of the same general region might be commingled. So also englacial material, by crevassing and by the descent of streams from the surface to the base, would be carried down to the bottom and mingled with the subglacial debris. So also blocks broken away from the base of the prominence which yielded the englacial erratics might be moved forward along the bottom parallel with the englacial material above, and lodged at any point along the line. It is therefore to be expected that the basal deposits will contain the same rock species as the englacial, but if there be no

process by which the basal material is carried upward the reve will not be the case, and there will be a clear distinction betw the englacial deposit and the subglacial deposit, in composit as well as physical state.

Not a few glacialists, however, advocate in somewhat dif ing forms and phases the doctrine that basal material is carr upward into the body of the glacier and at length reaches surface, and that at the extremity of the ice this is comming with any erratics that may be englacial or superglacial by orig derivation. This doctrine appears to have had its origin in endeavor to explain the very common fact that glacial drift been carried from lower to higher altitudes. Erratics are o found lodged several hundred feet higher than the outcrop f which they were derived. It has never seemed to me, howe that this phenomenon necessarily was different in kind from which takes place in the bottom of every stream; at lea have not come in contact with any instances that seeme require a different explanation, except those connected kames and eskers that require a special explanation in case. We are so accustomed to view streams from above, so accustomed to study the extinct glaciers from the bot that we are liable to overlook the community of some of simpler processes involved alike in both phenomena. dictum that water never runs up hill is measurably true of surface currents of the ice as well as water, but it altog fails when applied to the basal currents of either. It is prol that there is no natural stream of any length in which, at part of its course, basal debris is not carried from low higher altitudes and lodged there. If the bed of any st were made dry and the debris in it critically examined, it v be found that at numerous points the silts or sands or gr had been carried from the bottom of some basin in its b the higher rim or bar or reef that bordered it on the d stream side. So I conceive that, on a grander scale, the n result of the flow of the basal ice of a continental glacier the inequalities of the country was the lifting of material

some of the lower horizons and its lodgment on the crests of ridges or the slopes or summits of mountains that lay athwart its course.

So again, it is certain that a considerable part of the peripheral drainage of glaciers takes place through tunnels beneath the ice. It is reasonable to suppose that during the winter season, when the drainage is slack, these tunnels tend to collapse in greater or less degree, under the continued pressure of the ice and the "fattening" of the glacier, so that in the early part of the next melting season the contracted tunnels may be overflooded by glacial waters. To the extent that these tunnels become incompetent the water would become ponded back in the crevasses and moulins by which the surface-water gains access to them. They thus come to have something of the force of water flowing in tubes, and may be presumed to be capable of forcing rounded material to some considerable height, and of carrying ice-imbedded boulders to any point reached by the stream. These tunnels probably undulate with the bottom, and lodgment along them takes place wherever enlargement permits.

Without, therefore, appealing to any upward cross currents within the ice itself, it is possible to explain the transportation of the drift from lower to higher altitudes. I have never seen phenomena of this kind that seemed to call for any other explanation than these. I am not prepared to say that there are no such phenomena. One of the purposes of this article will have been accomplished, if it shall call forth a critical statement of phenomena that require the assumption of internal upward movements of the ice to account for them, and of the criteria which distinguish such phenomena from those that may be referred to upward basal movements such as are common to all streams or to the exceptionally conditioned subglacial streams. That there are upward internal movements in most streams is as much beyond question as the existence of upward basal currents in rivers and glaciers, but they are dependent chiefly upon the velocity of the current and the irregularity of the bottom.

Theoretically, as I understand, a stream moving in a strai course on a perfectly smooth bottom would not develop upward cross current. Each lower layer would move slo than that above it by reason of basal friction, but they wo move on in parallel lines. But if irregularity of bottom introduced the parallelism is obviously destroyed, and if velocity be high so that the momentum of the particles beco great relative to their cohesion, irregular internal movem will result, and these will often be of a rotary nature in vert planes bringing the basal parts of the fluid to the surface or reverse. For this reason rapid streams abound in rotary curre while slow streams do not.

Now it is quite obvious that a stream of water moving rate of three or four feet per day, or even fifty or sixty feet day, would not develop perceptible upward currents, and certa would not lift the lightest silt from its bottom. I do not t there are any theoretical grounds for believing that inte glacial currents are developed, which flow from base to sur carrying bottom debris to the top.

One of the most remarkable expressions of the phenomena of the Upper Mississippi region consists of bel boulders stretching for great distances over the face o country, and disposing themselves in great loops after fashion of the terminal moraines of the region with which are intimately connected. Besides this, there are num patches of boulders of more or less irregular form and unce relations. The whole of these have not been studied in d but a sufficient portion of them have received careful exar tion to justify the drawing of certain conclusions from t Those which have been most studied lie in Ohio, Ind Illinois, Michigan, Wisconsin, Iowa and Dakota. Those o first three States have been most carefully traced and their stitution is such as to give them the greatest discrimin value. To these our discussion will be limited chiefly.[1]

[1] Parts of these tracts were long since described by Bradley of the Illinois (Geol. Surv. Ill., Vol. IV. p. 227). Collet of the Indiana Survey (An. Rep.

Emerging from the dunes at a point north of the Iroquois river in Jasper county, northwestern Indiana, a well characterized belt of surface boulders stretches westward to the State line, just beyond which it curves about to the south and then to the east, and re-enters Indiana a little south of the northwest corner of Benton county. It soon turns abruptly to the south and reaches the Wabash river near the centre of Warren county. The immediate valley of the Wabash is thickly strewn with boulders from the point where the belt reaches it to the vicinity of West Point on the western line of Tippecanoe county. The uplands, however, do not give any clear indication of the continuity of the belt, and the connection is not altogether certain. There is an inner well-marked belt that branches away from this in the central part of Benton county and runs southeasterly into the northwestern quarter of Tippecanoe county, beyond which only scattered boulders occur, which leaves its precise connections also in doubt. But starting from West Point, which is less than a dozen miles from the point where the two belts cease to be traceable with certainty, a well-defined belt, one or two miles wide, runs southeasterly across the southwestern corner of Tippecanoe county and the northeastern quarter of Montgomery county to the vicinity of Darlington, beyond which its connection is again obscure, although boulders occur frequently between this point and the northwestern corner of Brown county, where boulders are very abundant. So also, patches of exceptionally abundant boulders occur in the west central part of Clinton county. These may be entitled to be regarded as a connecting link between the train which enters northwestern Tippecanoe county and that of northwestern Boone county, as scattered boulders of the surface type, but of not very exceptionally frequent occurrence, lie between them. However this may be, a belt of much more than usually frequent surface boulders stretches southeasterly to the vicinity of Indianapolis,

p. 404) and Orton and Hussey of the Ohio Survey (Geol. Surv. Ohio, Vol. III., pp. 412, 414 and 475). The relationship of these tracts to morainic lines and to each other I worked out some years since (Third An. Rep. U. S. G. S. pp. 331, 332, 334) but I owe many details and some important additions to my associate, Mr. Leverett.

and probably connects with a very well-marked belt lying n the south line of the southeast quarter of Marion county anc the northeastern part of Johnson county. There is also a w defined tract in southeastern Hendricks county, running east west, without evident connection with the foregoing tra though it may be the equivalent of the Darlington belt. Tl is also a somewhat unusual aggregation in the form of irreg belts in southeastern Johnson county, in the vicinity of Nine and in southern Shelby county. The belt south of Indianap is probably to be correlated by scattered boulders only slig more abundant than those of the adjacent region, but of surface type, stretching northeasterly to near the center of west half of Henry county, where a well-marked belt again in. From this point the tract runs northeasterly nearly to north limit of the county, where it turns easterly and runs ir vicinity of the line between Randolph and Wayne countie near the Ohio line, where it curves to the southeast ente Ohio near the northwest corner of Preble county. In its sc easterly course across that county it is phenomenally devel as has been well shown by the descriptions of Professor O Soon after entering Montgomery county it curves about northeasterly course, and crossing the great Miami river, miles above Dayton, holds its northeast course across the s eastern part of Miami county, the northwestern part of C paign county, and thence on to about the center of L county, where it curves about and runs in a direction a littl of south to near the southeast corner of Champaign co beyond which it ceases to be a specially notable phenomen

In the region between the Wabash and Kankakee rive northern Indiana, there are numerous tracts of irregular over which surface boulders in phenomenal abundanc scattered. These are particularly noticeable in southern J county; in the vicinity of Wolcott, Monon and Chalm White county; near Star City in Pulaski county; in the s eastern corner of Stark county, and very generally alon great interlobate moraines, lying parallel with the Eel

and some others of the Saginaw glacial lobe. These are so associated with the inter-tangled morainic phenomena of that region as not to admit of convenient and brief description in their genetic relationships.

The well-defined tracts have a most significant distribution. The first part described is associated with the terminal moraine that marked the margin of a lobe of ice that moved westward along the axis of the Iroquois basin to a point a few miles beyond the Indiana-Illinois line. The portion that runs southward to the Wabash is associated with the moraine that follows the same course, and runs at right angles over the older moraines of the Lake Michigan lobe. The tract in Tippecanoe and Montgomery counties, that in south Marion county, and that in Henry and Randolph counties, in the eastern part of the state, are associated with the terminal moraines that form a broad loop with the West White river basin lying in its axis. In western Ohio the belt is intimately associated with a moraine that bordered the Miami lobe of the ice sheet, and the south-trending portion in eastern Logan and Champaign counties lies on the western margin of the Scioto lobe.

The relationship of these tracts to terminal moraines is very clear and specific. They constitute marginal phenomena of the ancient ice sheet. Their distribution completely excludes their reference to floating ice, for they not only undulate over the surface utterly negligent of any horizontal distribution, but they are disposed in loops in crossing the basins of the region, and the convexities of these loops are turned down stream. These basins for the most part open out in southerly or westerly directions which makes it improbable that ice-bearing bodies of water occupied them. But if this were not fatal, certainly the fact that the convexities of the boulder belts are turned down stream and cross the centers of the basins is precisely contrary to the distribution they must have assumed if they were due to floating ice in bodies of water occupying the basins. I hold it, therefore, to be beyond rational question that these tracts were deposited as we find them by the margins of the glacial lobes that invaded the region.

If these boulder belts were of the same nature as the avei boulders of the till - sheets beneath them, then the simple fa unusual aggregation might be plausibly referred to the accid of gathering and deposition. But they are very clearly di guished from the average boulders of the till by sev characteristics.

1. They are superficial. Sometimes they rest completel the surface, sometimes they are very slightly imbedded, sc times half buried, sometimes they protrude but a slight por and sometimes they are entirely concealed, but lie immedi at the surface. In all cases the aggregation is distinctly su ficial. Where they are buried, the burying material is usuall different texture and composition from the subjacent till, appears to be distinct in origin from it. The superficiality o tract is very obvious almost everywhere, and is especially regions where the subjacent till is of the pebble - clay r than boulder - clay order, for the comparative absence of b ers below emphasizes the contrast. Throughout most of region the subjacent till is not of a very bouldery type, so the distinction is generally a marked one.

2. The boulders of the belts are almost without exce derivatives from the crystalline terranes of Canada. Thc the great tract especially under consideration were derived the typical Huronian rocks of the region north of Lake H and from granitic and gneissoid rocks referable to the La tian series of the same region. These last, however, cann sharply distinguished from the granitic rocks derived other parts of the Laurentian terrane. The Huronian rock very easily identified because of the peculiarities of some species. Among these the one most conspicuously charact is a quartz - and - jasper conglomerate. The matrix is usu whitish quartzite. This is studded with pebbles of typica jasper and of duller rocks of jasperoid nature, which thence into typical quartzite pebbles. With these are mi crystalline pebbles of other varieties. Another peculiar comes from the "slate conglomerate" of Logan. It consi

a slaty matrix through which are scattered rather distantly pebbles of granitic, quartzitic and other crystalline rocks. This is one of the forms of the "basal conglomerate" of Irving. Other varieties of this "basal conglomerate" are present. In addition to these very peculiar rocks, a quartzite of a very light greenish semi-translucent hue has a wide distribution along the tract. It is readily distinguishable from the numerous other quartzites of the drift of the interior. Some years since, on returning from my first field examination of a portion of this belt, I sent a typical series of chips from the characteristic erratics to Professor Irving, who had recently returned from the study of the original Huronian region. He returned a suite of chippings that matched them perfectly throughout, all of which were taken *in situ* in the region north of Lake Huron.

Among the boulders of the belt are occasionally found specimens of impure limestone or of limy sandstone that might perhaps be referred doubtfully to some member of the paleozoic series; but on the other hand, might with equal or greater probability perhaps be referred to the similar rocks of the Huronian series. These are quite rare, never forming, so far as my observations go, as much as one per cent. of the series. In the several definite enumerations made to determine the percentage of the doubtful specimens, the result never exceeded a fraction of one per cent. In the most extensive enumeration the result was about one-half of one per cent. Aside from these doubtful specimens there are practically no boulders in the belts that can be referred to any of the paleozoic rocks that intervene in the 500 miles between the parent series north of Lake Huron and the tract over which the boulders are now strewn. Occasionally there may be seen erratics from the paleozoic series at or near the surface, but they are not usually so disposed on the surface as to appear to be true members of the superficial boulder tract. There is, therefore, the amplest ground for the assertion that these boulder tracts are of distant derivation, and that they are essentially uncommingled with derivatives from the intermediate region.

3. The boulders of this series are much more angular t those of the typical till sheets. Some of them, indeed, rounded, but the rounding is generally of the type which bo ers derived by surface degradation and exfoliation pres They rarely have the forms that are distinctively glacial. Q a large percentage are notably angular, and have neither suff glacial rounding nor spherical exfoliation. Some few are cially worn and scratched, but the percentage of thes small.

The tracts therefore present these four salient charact tics: (1) the boulders are derived from distant crysta terranes (400 to 500 miles) and are essentially uncommin with rock from the intervening paleozoic terranes; (2) the essentially superficial, and the associated earthy material l texture differing from that of the subglacial tills; (3) the notably angular and free from glacial abrasion, except in n degree; (4) the tracts are so associated with terminal mor and so related to the topography of the region, that there rational ground for doubt that the boulders were borne to present places by the glaciers that produced the corre moraines.

In contrast to these superficial boulder formations, th sheets below are made up of a very large percentage of g clay whose constitution shows that it was produced in pa the grinding down of the paleozoic series. In this are imb boulders and pebbles that were derived from the paleozoic as indicated by their petrological character, and, in instances, demonstrated by contained fossils. While a part of the boulders contained in the till are angular o slightly worn, the larger part are blunted, bruised, scratche polished by typical glacial action. This obvious grinding boulders, taken in connection with the clay product res from the grinding, affords a clear demonstration that the d was produced at the base of the ice by its pushing, dra rolling action.

The two formations, therefore, stand in sharp contra

one indicating the passive transporting action of the ice in bearing from their distant homes north of the lakes the crystalline boulders and dropping them quietly on the surface, the other indicating the active dynamic function of the ice in rubbing, bruising and scoring the material at its base. The one seems to me a clear instance of englacial and superglacial transportation; the other an equally clear example of subglacial push, drag and kneading.

Now if it were the habit of an ice-sheet of this kind to carry material from its bottom to the surface by internal movement, it would seem that the distance of 400 to 500 miles which intervened between the source of the crystallines and the place of their deposit would have furnished ample opportunity for its exercise, and that there would have been commingled with the englacial and superglacial material many derivatives from the intermediate region, and these derivatives should have borne the characteristic markings received by them while at the base of the ice. The very conspicuous absence of such commingling, and the absence or phenomenal rarity of anything that even looks like such a commingling, appears to me to testify in quite unmistakable terms to the distinctness of the methods of transportation. In view of the great territory over which this particular belt is spread, and the greater territory which is embraced in the other tracts not here specially considered, there is left little ground for doubt that this distinctness of englacial from basal transportation was a prevailing fact and not an exceptional one. This is supported by concurrent evidence derived from the territory west of Lake Michigan. This territory unfortunately does not bear erratics that have equally distinct characteristics, but, so far as my observation goes, the phenomena are alike throughout. I am therefore brought to the conclusion that, in the interior at least, there was no habitual lifting of boulders from the base of the ice sheets to the surface, nor any habitual commingling of basal with englacial and superglacial material, except, of course, as it took place by virtue of the falling of the latter through crevasses to the base, and by mechanical intermixture of the two at the edge of the ice.

The amount of englacial till under this view is little m than that which was lodged in the body of the ice in its pass over the knobs and ridges of the hilly and semi-mountain regions of the north. To this is perhaps to be added occasio derivatives from the more abrupt prominences of the paleoz region and the superficial dust blown upon the ice from surrounding land, which was probably the chief source of silty material intermingled with the superficial boulders. total amount is thus quite small, though important in its nificance

The eskers and kames of the region are made up of der tives from the basal material as shown by (1) the local origi the material in large part, (2) the mechanical origin of sands and silts, (3) the not infrequent glacial markings of pebbles and boulders, and (4) the disturbed stratification of beds.[1] If I am correct in respect to the kind and amoun the englacial and superglacial material, it is obvious that es and kames, such as are found in the interior, could not be der from englacial or superglacial sources. The term englaci here used does not include such materials as may be lodge the basal stratum of the ice and brought down to the ac bottom by basal melting.

The conclusions drawn from the phenomena of the p of the interior are not necessarily applicable to more hill mountainous regions.

T. C. CHAMBERLIN.

[1] See "Hillocks of Angular Gravel and Disturbed Stratification," Am. Jou Vol. XXVII., May 1884, pp. 378–390.

Studies for Students.

DISTINCT GLACIAL EPOCHS, AND THE CRITERIA FOR THEIR RECOGNITION.[1]

I. Introduction.

It has long been evident that writers on glacial geology are not at one concerning some of the important questions which underlie the interpretation of the history of the glacial period. Certain recent publications have served to emphasize the differences between them. There are two questions, at least, concerning which there must be agreement, or at any rate a common understanding, before existing differences can be eliminated or justly evaluated. When the answers to these questions have been agreed upon, or when the positions of the contending parties are clearly understood, it may be found that some of the apparent antagonisms have no better basis than differences in definition. Stated interrogatively, the two questions referred to are these: 1. What constitutes a glacial epoch as distinct from other glacial epochs? and 2. What are the criteria for the recognition of distinct glacial epochs, if such there were?

II. The Idea of a Glacial Epoch.

It is conceivable that, after the development and extension of a continental ice-sheet, it might be wholly wasted away. The maximum extension of such an ice-sheet would mark the culmination of a glacial epoch. If subsequently another ice-sheet of considerable dimensions were accumulated, its development and extension would constitute a second glacial epoch. These successive ice-sheets might be so related to each other in

[1] Read before the American Geological Society at Ottawa, Dec., 1892.

time, in position, and in the sequence of geological events, a be regarded as separate epochs of the same glacial period.[1] the other hand they might be so widely separated from e other in time, in position, and in the sequence of geolog events, as to make their reference to separate glacial peri more appropriate. In any case their separatión would be s ciently marked to necessitate their reference to separate epochs. So far we believe there would be no disagreement.

If, instead of entirely disappearing, the first ice-sheet suff great reduction of volume and area, and if this reduction followed by a second great expansion of the ice, might the of such expansion be regarded as a second glacial epoch of common glacial period? To this question, too, as thus st we apprehend there would be but one answer, and that mative.

It seems certain that the edge of the continental ice-s was subject to more or less extensive oscillations, as are the of glaciers and the edges of ice-sheets to-day. How muc an oscillation is necessary, and under what attendant condi must it take place, in order that the recession of the ice- shall mark an interglacial and its readvance a distinct g epoch? When the question takes this specific form, and inquiry is made concerning the quantitative value of the d ent elements entering into the problem, we reach the b ground. It is the battled ground, partly because it is the g of misunderstanding. It is the ground of misunderstar partly because glacialists are not agreed as to the meani certain terms in common use by them.

Four elements seem to enter into the idea of an ice as distinct from other ice epochs. These are (1) the dista which the ice retreated between successive advances; (duration of the retreat, or the time which elapsed betwee cessive ice extensions; (3) the temperature of the region from ice during the time between maxima of advance; a

[1] The terms period and epoch are here used in the sense in which they h used most commonly in the literature of glacial geology in the United States.

the intervention between successive advances, of changes interrupting the continuity of geological processes.

(1.) It would be arbitrary to name any definite distance to which the ice must recede in order to constitute its re-advance a distinct ice epoch. It would be not so much a question of miles as a question of proportions. Considering this point alone, we presume it would be agreed that an ice-sheet should have suffered the loss of a very considerable proportion of its mass, and that it should have dwindled to proportions very much less than those subsequently attained, before its re-advance could properly be called a separate glacial epoch. To be specific, if the North American ice-sheet, after its maximum extension, retreated so far as to free the whole of the United States from ice, we should be inclined to regard a re-advance as marking a distinct ice epoch of the same glacial period, if in such re-advance the ice reached an extension comparable with that of the earlier ice-sheet. Especially should we be inclined to refer the second ice advance to a second glacial epoch, if it, as well as the preceding retreat, were accompanied by favoring phases of some or all the other three elements entering into the notion of a glacial epoch. In this statement we do not overlook the fact that a northerly region—as Labrador or Greenland—might be continuously covered with ice throughout the time of the two glaciations of the more southerly regions. But this is not regarded as a sufficient reason for discarding the notion of duality. Greenland has very likely been experiencing continuous glaciation since a time antedating that of our first glacial deposits. The renewal to-day of glaciation comparable in extent to that of the glacial period would certainly be regarded as a distinct glacial epoch, if not a distinct glacial period, even though Greenland's glaciation may not have been interrupted. Scandinavia and Switzerland have probably not been freed from ice since the glacial period. Their snow and ice fields are probably the direct descendants of the ice fields of the glacial period. An expansion of the existing bodies of ice in these countries to their former dimensions, would constitute a new glacial epoch, if not a new glacial period.

Analogous subdivisions in pre-Pleistocene formations have b frequently recognized.

(2) The application of the time element is hardly s ceptible of quantitative statement. We are inclined to think t it would be generally agreed that, with a given amount of rec sion of the ice, its re-advance would be more properly regar as a distinct glacial epoch if the interval which had elap since the first advance were long. Whether a longer ti between the separate advances might reduce the amount recession necessary in order to constitute the second advanc second epoch, we are not prepared to assert; but we are incli to think it might.

(3) The third element is perhaps somewhat more tang than the second. If, during the retreat of the ice, the climate region which was twice glaciated became as temperate as th the present day in the same locality, we should be incline regard the preceding and succeeding glaciations as distinct epochs, especially if the intervening recession were great an duration long.

Unfortunately for simplicity and ease of determination, t are difficulties in determining with precision how far the retreated between successive maxima of advance, how long interval during which it remained in retreat, and the exte which the climate was ameliorated, as compared with that w went before and that which followed.

(4) If changes of any sort which interrupt the conti of geological processes intervened between successive ma of advance of the ice, the separation of the later adv from the earlier, as a distinct ice epoch, would be fav How great the intervening changes should be in orde constitute the re-advance a distinct ice epoch, is a concerning which there might be difference of opinion. I is altogether possible that such changes might intervene as to give sufficient basis for the separation. Orographic moven resulting either in continental changes of altitude or attitu among the events which might come in to separate on

epoch from another. Changes of this sort have often furnished the basis for the major and minor divisions of time in other parts of geological history, so that there can be no question as to their adequacy, if they were of sufficient magnitude. We hold that the intervention of orographic or other important geologic changes might reduce to a minimum the amount of recession, the duration of the recession, and the warmth of the intervening climate necessary to constitute the separate ice advances separate ice epochs. The absence of great orographic or other changes in glaciated regions between successive advances of the ice would be no proof that such advances should not be regarded as separate epochs. Divisions of equal importance have often been made without evidence of such changes.

From the foregoing discussion, brief as it is, it will be seen that within certain narrow limits the definition of a glacial epoch, as distinct from other glacial epochs, must be more or less arbitrary. It is less important that an arbitrary definition should be accepted, than that the same meaning should be attached to technical terms in common use among geologists. In the interest of harmony and of a common understanding, and without the violation of any truth of science, we believe it would be well if the conception of a glacial epoch, as framed by those who are our leaders in position and in fact, were made the basis for our usage of the term.

III. The Criteria of Distinct Glacial Epochs.

If there have been differences of opinion concerning the nature of ice epochs, as distinct from each other and from ice periods, there has been a failure to adequately apprehend the nature, the extent, and the meaning of the real criteria on which the final recognition of separate ice epochs, if such there were, must be based.

Such criteria are several in number. They are of unequal value. In some instances a single one of them might be quite sufficient to establish the fact of two ice epochs. In other cases, single criteria which might not be in themselves demonstra-

tive, have great corroborative weight, when found in associatio with others. In all cases, much discretion much be used in tl interpretation of these criteria. They may be enumerated und several specific heads.

(1) *Forest Beds.* Beds of vegetal deposits or old soils a frequently found between layers of glacial drift. This is one the criteria most commonly cited, because it is of common occu rence and easy of recognition. The advocates of the unity the glacial period maintain that such beds of organic matt might become interbedded with morainic debris during min oscillations of the ice's edge. The phenomena of existing gl ciers make it evident that forest beds or soils might be enclos by the deposits of an oscillating ice edge. By repeated oscil tions of the ice's edge during the general retreat of the ice, su vegetal beds might become interstratified with glacial drift m or less frequently over all the area once covered by the ice, a from which it has now disappeared. The mere presence of ve table material between beds of drift is therefore no proof of c tinct ice epochs. This does not destroy the value of the ve tal beds as a criterion for the recognition of distinct ice epoc but it makes caution necessary in its application. It does follow that, since *some* inter-drift forest-beds do not prove in glacial epochs, *none* do. The question is not how forest-b might originate, but how existing forest-beds did originate.

Where the plant-remains found in the relations indicated so well preserved as to make identification of the species po ble, we have a means of determining, with some degree accuracy, the climatic conditions which must have obtained at place where the plants grew during the time of their life. these interbedded plant-remains are of such a character a indicate a temperate climate, we can not suppose that they g at the immediate edge of the ice, and therefore that they buried beneath its oscillating margin. To be specific, if inter-drift plant remains in any given locality of the area covered by ice are such as to indicate a climate *as warm as present in the same locality*, the ice must have receded so fa

the northward that its re-advance might, in our judgment, appropriately be regarded as a separate ice epoch.

It has been suggested in opposition that temperate conditions may obtain even up to the edge of the ice, and that interbedded vegetal remains indicating temperate climate do not prove any considerable recession of the ice. The phenomena about existing glaciers have been appealed to in support of this demurrer. But the objection is not well taken. The climatic conditions which obtain about the borders of small, local glaciers, are not a safe guide as to climatic conditions which obtained about the margin of a continental ice-sheet, any more than the climatic conditions which obtain about a small inland lake are a safe criterion as to the climatic conditions about a sea-coast. The general principles of climatology, as well as specific facts concerning plant distribution, seem to us to indicate that the climate about the border of a continental ice-sheet must have been arctic.

It is evident that the greater the distance north of the overlying drift remains of temperate plants are found, the more conclusive becomes the evidence. Plant remains indicating temperate climate at the very margin of the drift sheet which overlies them, would be less conclusive than similar evidences one hundred miles to the northward. It might be difficult to prove in any given instance that the ice which deposited the drift overlying plant remains advanced one hundred miles, or any other specific distance, south of any particular underlying forest bed. If the forest bed were continuous for the whole distance, the case would be clear. It would also be conclusive if the continuity of the drift overlying a forest bed at any point with that of a remote point to the south, could be demonstrated. In spite of these difficulties in its application, the vegetal beds constitute a valuable criterion in making the discriminations under consideration, when they are properly applied. Under proper circumstances the criterion may be conclusive when taken alone, and it may have corroborative significance when not itself conclusive.

The absence of forest beds and of all traces of vegetal deposits whatsoever between beds of drift, is no proof of the absence of

recurrent ice epochs, since the second advance of the ice might have destroyed all trace of the preëxistent soil and its vegetal life. It is always possible, too, that such beds exist, even if they have not been discovered. It would have been anticipated that they would not be abundant, or wide spread. The absence of forest beds is therefore at best no more than negative evidence.

(2) *Remains of Land Animals.* Bones of mammalia or remains of other land animals, occurring in relations similar to those in which forest beds occur, may have a like significance. Their value as a criterion of separate glacial epochs is subject to essentially the same limitations as forest beds.

(3) *Inorganic Products formed during a time of Ice Recession.* The recession of the ice after a maximum of advance would leave a land surface more or less affected with marshes and ponds. In such situations, bog iron ore might accumulate, if conditions were favorable. Such ore beds, buried by the drift of a later ice advance, would have a significance comparable to that of forest beds, except that they would give less definite information as to climate, and would be correspondingly less trustworthy. Should such ore beds be found in such relations as to prove that the underlying and overlying bodies of drift were deposited by ice sheets which extended great distances further south, their significance would be enhanced. From the thickness of the ore beds some inference might be drawn as to the length of time concerned in their accumulation. But because of the variable rate at which bog ore may accumulate, such inference should be used with caution.

Concretions of iron oxide might be formed in the marshes or in ill-drained drift areas where accumulations of greater extent were not made. A subsequent incursion of the ice might incorporate these nodules with its drift, wearing and striating them as other stones, and depositing them as constituent parts of the later drift. Such iron nodules in the later drift would mean a recession and re-advance of the ice with some considerable interval between, although not necessarily an interval sufficiently

warm or long to be regarded as an interglacial epoch.[1] Calcareous concretions, like those of the loess, would possess a like significance, in like relations. While in themselves these inorganic products of a time of ice recession might fail to be conclusive of separate ice epochs, they might have much corroborative significance when associated with other phenomena. An inter-till iron ore bed, associated with a forest bed which indicated a warm climate, would be most significant.

The absence of knowledge of ore beds between sheets of till, and the absence from an upper bed of till of concretions of iron and lime carbonate formed during a recession of the ice, would be no proof that interglacial epochs did not occur. These products were probably formed in relatively few localities. They stood good chance of destruction at the hands of the returning ice, and they may exist, where they have not been discovered, or where their significance has not been understood. Their absence is at best no more than negative evidence.

(4) *Beds of Marine and Lacustrine Origin.* If between beds of glacial drift there be found beds of lacustrine or of marine origin, such beds would indicate a recession of the ice during their time of deposition. Their position would be a minimum measure of ice recession. If such lacustrine beds contain organic remains, they will bear testimony concerning the climatic conditions which existed where they occur, at the time of their deposition. If the fossils in such beds denote a temperate climate, or a climate as mild as that of the present day in the same region, the ice must have receded so far to the northward as, in our judgment, to constitute its re-advance a distinct ice epoch. This line of argument may be even stronger than that drawn from remains of terrestrial life, since the ice would probably affect the temperature of the sea to greater distances than that of the land, and affect it to a greater degree within a given distance. The argument becomes stronger the further north the inter-drift marine and lacustrine deposits occur, since the ice must always

[1]This point concerning iron nodules was suggested to the writer by Mr. W. J. McGee.

have receded to a position still further north. If marine lacustrine beds lying far north of the later ice limit conta proof of temperate climate, the argument becomes conclusive.

The absence of marine and lacustrine deposits between be of drift, would be no proof that interglacial epochs did n occur. Lacustrine beds could be made only where there we lakes, and lakes would be the exception rather than the ru Marine beds in similar positions would rarely be known, exce where a definite succession of changes of level has taken pla Both classes of deposits, if once formed, would be subject destruction by the over-riding ice of a later epoch, if such th were. Neither would be likely to be preserved at all poi where formed, and both may exist at many points where th existence is not known. The absence of these beds is at b no more than negative evidence.

(5) *Beds of Subaërial Gravel, Sand and Silt.* Layers of strati drift between layers of ground moraine, are of common occurre in many regions. Under ordinary conditions their existenc not regarded as evidence that the underlying and overlying are to be referred to separate ice epochs. But it is conceiva that beds of stratified drift may, under the proper circumsta and relations, be strong evidence of separate ice epochs. last stages of ice work in the glacial period were accompanied many regions, by the deposition upon adjacent land surfaces extensive bodies of gravel and sand, washed on beyond the by waters issuing from it. Except in valleys through w strong currents coursed, such deposits were apparently not ried far beyond the edge of the ice. But as the edge of th withdrew to the northward, sand plains may have exter themselves in the same direction, by additions to their ice-v faces. It is conceivable that the process of subaërial building at the edge of a receding phase of ice, migh carried so far under favorable circumstances, as to result in construction of plains of great extent. In this event, a su quent ice-advance might overspread such plains in such as to bury, without destroying them, though such a cour

events would certainly be exceptional. In order to constitute the inter-stratified gravel and sand evidence of separate ice-epochs, its continuity for great distances between beds of till, and in the direction of ice movement, would need to be demonstrated. In themselves, these beds, under the conditions indicated, would simply be a minimum measure of the amount of ice recession between the deposition of the underlying and overlying bodies of till. It is hardly likely, though possible, that the continuity of inter-bedded gravel and sand could be proved for a sufficient distance north of the southern limit of the less extensive bed of ground moraine, to alone constitute evidence of a recession of ice great enough to make it necessary to refer its re-advance to a new epoch. Beds of silt in like relations, deposited by waters beyond the edge of the ice, would have a like significance so far as the question here under consideration is concerned. Such beds of stratified drift might sometimes have corroborative value when their testimony, taken by itself, is inconclusive. If, for example, their surfaces are marked by forest beds, and especially by forest beds whose plants denote a warm climate, the association becomes most significant.

In view of what has been said, it is evident that the absence of beds of subaërially stratified silt, sand, and gravel, between beds of till can not be brought in evidence against separate ice epochs. It would rarely be true that topographic and hydrographic conditions would make possible the construction of plains of sufficient extent to serve as criteria for the purpose here indicated, and few of those formed would escape such a degree of destruction as to leave them demonstrably continuous. There is also the further possibility that such beds exist, even though their continuity be not known. To prove the continuity of a buried bed of stratified and incoherent drift, even if it existed, would be a most difficult task.

(6) *Differential Weathering.* If, after covering a given region, the ice retreated, the drift which it left in the area which it previously covered would be subject to oxidation, leaching and disintegration. The depth to which this oxidation, leaching

and disintegration would extend, would be dependent upon th length of time during which the drift was exposed, and upc the climate which affected the region during its exposure. Tl longer the exposure and the warmer the climate, the deeper woul the weathering extend. If, subsequently, the ice extende over the same region, it might, in some places, override ar bury the old surface without destroying it. The earlier oxidiz and leached drift would thus come to be buried by the newer, u oxidized, unleached drift. If, therefore, beneath the newer dr of any given locality there be found a lower drift, the surface which is oxidized and leached to a considerable depth, the e dence is strong that the lower drift was exposed for a long peri of time before the upper drift was deposited upon it. With certain limits a similar result might be brought about, it is tr if the ice, after having reached a certain maximum stage of a vance, were to retreat for a short distance only and there rem for a very long period of time. A subsequent minor advar might bury the oxidized surface of the drift beyond the pc tion of the long ice-halt. Under these conditions, the clim which would have obtained in the area of the drift exposed duri the minor retreat would have been cold, and oxidation, leachi and disintegration would have proceeded slowly. If they reacl considerable depths, the time involved must have been v long. If this surface of oxidized and leached and disintegra drift were found to reach far to the northward beneath the la of newer and upper drift, it would indicate a great recessior the ice. We maintain that if it were found sufficiently far nc of the margin of the overlying drift, and if its depth were sı ciently great, extending well down below any possible accum tion of superglacial till, it might be a positive criterion of so g a recession of the ice, protracted through so great an inte of time, as to constitute its new advance a separate ice epoc

There is much reason to believe that the soil develo under the influence of a warm climate differs in some resp from one developed from similar material under other conditi The well-known fact that red and reddish soils are especi

characteristic of low latitudes and warm climates is significant. If therefore a soil developed on the surface of one sheet of drift and buried by another, be found to possess, in addition to unmistakable marks of long exposure, the peculiar marks which seem to be characteristic of soils developed under high temperatures, the argument gains in strength.

This argument from oxidation and weathering has another application. If in a later advance, following a protracted recession, the ice-sheet failed to reach the limit of its earlier advance, there would remain an area of drift deposited by the first ice-sheet, outside the drift deposited by the later. Now if the time interval between these two advances was great, and especially if during this interval the climate was mild, the oxidation and weathering of the older drift surface would be markedly different in degree from that of the newer. If, under these circumstances, the surface of the older sheet were found to be weathered and oxidized and reddened up to the border of the newer drift sheet, and if here there were found to be a sudden change in the character of the surface of the drift so far as depth and degree of oxidization and weathering is concerned, we should have strong evidence that the one sheet of drift was much older than the other. The statement sometimes urged that the drift which was deposited near the edge of the greatest ice advance would be largely made up of the residual materials which occupied the surface invaded by the ice, would not meet the case. For if it be granted that this statement is qualitatively good, we should find the greatest degree of weathering and oxidation at the extreme margin of the drift, and it should be found to be less and less on receding from this margin. There would in this case be no sudden transition from a deeply weathered and oxidized surface, to one which is fresh and unoxidized, along a definite line. We maintain that if the whole of the drift deposits are referable to one epoch, there should be no sudden transition in the surface of the drift from that which is deeply weathered to that which is not, the one surface being separated from the other by a definite and readily traceable line.

It has been urged against the criterion of differential wea ering that superglacial material is or may be thoroughly oxidi before its deposition, and that a layer of oxidized drift betw layers of till may be no more than superglacial debris deposi during a minor recession of the ice.[1] We believe that attempt to eliminate the value of this criterion rests partly on exaggerated idea concerning the amount of superglacial mater but more especially on a failure to apprehend the real mean of the argument for the validity of the criterion, and upo failure to note the limitations imposed upon it by its advoca It is not affirmed that a layer of oxidized drift between beds unoxidized drift is *per se* proof of two glacial epochs; but i affirmed that if such layer of weathered drift can be shown extend far below any possible superglacial till, into the glacial till below, in such wise as to indicate that it is the re of subaërial exposure in a warm climate subsequent to deposition and prior to the deposition of the overlying til constitutes the best possible evidence of an interglacial ep especially when accompanied by the corroborative testimon other criteria. It is further affirmed that if the second shee drift failed to reach the limit of the first, and if the drift w was deposited by the first and never covered by the second sheet, is more thoroughly and more deeply weathered than deposited by the second, and especially if the two types of surface meet along a definite and readily traceable line, the ment becomes, in our judgment, irrefragable. In its applica this criterion would be infallible only in the hands of one could distinguish between superglacial and superglacially oxi material on the one hand, and material subaërially weat after its deposition, on the other.

In circumstances and relations where the weathering c drift is not in itself conclusive, it might still have corro tive value in association with other lines of evidence.

The absence of an oxidized and disintegrated zone of

[1] This point was urged at the reading of the paper at Ottawa, by Prof. Hitchcock, Mr. Upham, and others.

below a superficial layer which is not oxidized, would be no proof that there were not distinct ice epochs, since the ice of any later epoch, if such there were, might have planed off the surface of the drift left by its predecessor to the depth of the weathering. The preservation of such surfaces after a second ice invasion must be regarded as the exception rather than as the rule. There is always the possibility, too, that an oxidized and weathered zone marking the surface of an older drift sheet exists, where excavations have not opened full sections of drift to view. The absence of weathered zones of drift beneath the surface, or the absence of knowledge of their existence, is therefore at best no more than negative evidence. The absence of greater weathering of the drift outside the limit of the drift supposed to belong to a later epoch, would be positive evidence against the reference of the two sheets of drift concerned to different epochs.

A specific part of the above line of evidence may be separately mentioned. One phase of weathering is the disintegration of boulders, and this is a point which can be readily applied even by those who are not geologists. If the boulders of one region are much more commonly disintegrated than those of another, and if the two regions are separated from each other by a well-marked boundary line, the inference lies close at hand that the boulders in the one case have been much longer exposed to disintegrating agencies than in the other. It is no answer to this argument to say that the materials lying at the very front of the drift deposits contain boulders which were derived from the disintegrated rock over which the ice has passed, and that they were therefore in a less firm state at the outset. In many cases these boulders have come from great distances, and coming from great distances they must have come in a firm and solid state, else they could not have suffered such extensive transportation, except indeed their position was superglacial throughout their whole journey. This argument has equal force when applied to the area covered by the two sheets of drift where two exist. If within the region of drift under investiga-

tion we find a surface layer of greater or less depth, the boul of which are hard and fresh, and if beneath this we find anot layer of drift, the stony material of which is largely disintegrat at least in its upper parts, we have good evidence that surface bearing the disintegrated boulders was exposed fo considerable length of time before the deposition of the ov lying drift, which carries fresh boulders. Since the disintegrat of boulders is only one phase of weathering, the limitati of this argument are identical with those already noted connection with the general argument from differen weathering.

(7) *Differential Subaërial Erosion.* If the drift deposited one ice-sheet were to be exposed for a considerable interva time, and if the ice in its subsequent advance failed to reach limit of its first invasion, the two areas should show diffe amounts of subaërial erosion, since the one has been expose the action of air and water much longer than the other. line which marks the limit of the later ice invasion should be line of more or less sudden transition from an area with where stream erosion has been greater, to an area within, w stream erosion has been less.

The point here made can not be met by the suggestion the greater erosion of the outer area was effected by the v issuing from the ice which had retreated to the position marked by the border of the area of the lesser erosion. S as we know, such waters would be depositing, not ero Furthermore, much of the erosion of the outer area would such relation to drainage lines that waters issuing from th could never have reached the localities where it is shown.

If the outer and older drift be found to have suffere times as much stream erosion as the inner and newer, it is f assume that it has been exposed something like ten tim long, if the conditions for erosion are equally favorable i two regions. The argument has especial weight if it ca found that beneath the newer drift the surface of the ol such as to indicate that it was deeply eroded before the

was placed upon it. The argument is stronger the farther from the margin of the newer drift such erosion on the surface of the underlying older drift can be proved to have taken place. In other words, if, in addition to the greater surface erosion of the older drift sheet as now exposed outside the limit of the newer drift, we find a notable unconformity between the newer and the older drift, and especially if this unconformity lie far enough north of the margin of the newer drift, the argument becomes conclusive.

When differential erosion and drift unconformities are not in themselves conclusive, they may have great corroborative value in conjunction with differential weathering, forest beds, or other indications of separate ice epochs.

The absence of observable unconformity between sheets of drift would be no proof that there were not distinct and widely separated ice epochs, since the later ice invasion might have so far modified the surface which it transgressed, as to destroy all patent evidences of unconformity. It would have been anticipated that distinct unconformities in the drift would be rare, even if there were distinct ice epochs, for the same reason that weathered zones and forest beds would be rare. But if the drift which lies outside a line supposed to mark the limit of a sheet of drift belonging to a later ice epoch, be not more eroded than that which lies within such line, the absence of greater erosion in the outer drift is positive evidence against the reference of the drift of the two areas to distinct ice epochs, if conditions for erosion in the two areas are equally favorable.

(8) *Valleys Excavated Between Successive Depositions of Drift.* A closely related, but not identical, point may be found in the extent of the valley excavations which can be proved to have taken place between the deposition of the earlier and later drift. We do not refer to valleys excavated in the drift especially, but to those excavated in other formations as well. If it can be shown, for example, that after the deposition of an earlier drift sheet, and before the deposition of a later, valleys were excavated which extended not merely into the drift itself, but far

beneath the drift into the underlying rock, these valleys would be conclusive evidence of a long interval between the deposition of the two bodies of drift. The argument is of especial force when such excavations in the rock beneath the drift can be shown to have taken place at great distances within the margin of the newer drift. For valleys in such situations imply that the ice had receded at least as far to the north as they lie, during the interval between the two drift depositions, and may be so situated as to show that the ice had wholly left the drainage basin where they occur.

The absence of evidences of deep valley excavations in any given region during a supposed interglacial epoch, is no proof that such interval did not exist. The conditions may not have been everywhere favorable for erosion within the limits of any narrowly circumscribed area, and the absence of interglacial valleys would be only negative evidence against an interglacial epoch. The absence of such evidence everywhere would bear against the existence of an interglacial epoch of much duration in such wise as to be more than negative evidence.

(9) *Different Directions of Movement.* If, after its maximum advance, the ice suffered merely a minor recession and then remained stationary, or nearly so, for a time, the general direction of its movement in a subsequent advance would probably be essentially the same as in the earlier. But if, after its maximum advance, the ice receded to a great distance, and especially if it entirely disappeared, a subsequent ice-sheet might have a very different direction of movement, since its center of accumulation and dispersion might be very different. It is conceivable that this center might shift during the history of a single ice-sheet. In this case there should be a gradual change in the direction of ice movement, not an abrupt one. If, therefore, there be found one sheet of drift made by an ice movement in one direction, overlaid by another sheet of drift deposited by ice moving in a very different direction, with an abrupt transition between them, such drift sheets would be presumptive evidence of distinct ice epochs. An exception would need to

be made in the case of drift sheets along the margins of confluent or proximate ice lobes. In such cases, if the one lobe temporarily secured the advantage of the other, drift beds formed by movements from opposite directions might be found in vertical succession, without being evidence of separate ice epochs.

It is no part of the purpose of this essay to point out the difficulties which might arise in the application of this criterion of diverse directions of ice movements. It is possible that gradual changes in the direction of movement might leave records which would seem to indicate abrupt changes instead. This possibility makes care necessary in the application of the criterion, but does not destroy its value. When not itself conclusive, this criterion may be so associated with differential weathering, differential erosion, forest beds, etc., that their combined testimony makes but one conclusion possible.

The absence of evidence of radically diverse directions of movement during the time of deposition of the various sheets of drift, would be no proof that there were not distinct epochs. In the first place, the movements of different epochs might be harmonious—a condition of things more probable than any other if the more common views of the causes of glaciation be correct. In the second place, if the movements were diverse, the deposits might still be so similar that their differentiation, when the one is buried, might not be easily made. In the third place, the later ice might have so far incorporated the older drift material with that which belonged more properly to it, as to have destroyed all definition between them.

(10) *The Superposition of Beds of Till of Different Physical Constitution.* After the retreat of an ice-sheet, the surface of the country thus discovered would be largely mantled with drift. This drift would serve to protect the underlying rock from disintegration. But where there was little or no drift, the rock surface would be subject to all the disrupting agencies which affect surface rocks. The same would be true of all rock surfaces bared by subaërial erosion after the disappearance of the ice.

Under these conditions, if a second sheet of ice invaded the region in question after it had been long exposed, it would find a surface prepared to yield large bowlders. The result would be the deposition of a new sheet of drift containing bowlders much larger than those which would have been proper to an ice-sheet overspreading a surface but recently abandoned. If, therefore, in the upper of two layers of subglacial till, bowlders of great size predominate, as compared with those of a lower homologous layer, they may be indicative of a great interval of time between the deposition of the upper and lower beds of drift. If the home of these bowlders be far north of the limit of the lesser sheet of drift, the distance, as well as the duration, of the ice retreat must have been great, and the reference of the two beds of till to distinct ice epochs would be favored. The case might be so strong as to make no other interpretation possible. Where in itself inconclusive, this criterion would have corroborative significance. In its application, the discrimination of subglacial and superglacial till would be imperative.

The absence of physical dissimilarity between superposed layers of subglacial till would not be proof of the absence of separate glacial epochs. The phenomena constituting the criterion could hardly be expected to be of common occurrence. They would never be obtrusive, and may easily have escaped attention where they exist.[1]

(11) *Varying Altitudes and Attitudes of the Land.* Another line of argument has to do with the altitude and attitude of the land during the deposition of various members of the drift complex. If during the deposition of one part of the drift that part of the continent covered by the outer part of the ice was low, the drainage from it would be sluggish. If the deposits of this drainage persist to the present time, we may find in their character evidence of the nature of the drainage, and therefore of the attitude of the land. If at a later time of drift deposition the glacial drainage in the same region was more vigorous,

[1] The 10th criterion, in the order here named, was suggested by Mr. McGee in the discussion which followed the reading of the paper at Ottawa.

the deposits made by the glacial streams would be correspondingly coarser. In these deposits, if they persist to the present day, we should find conclusive evidence of the swiftness of the streams. If it can be shown that during the deposition of one sheet of drift drainage was sluggish, and that during the deposition of a later body of drift the drainage was vigorous, these facts are evidence of an interval between the two times of drift deposition, sufficiently long to accomplish the corresponding changes in elevation or attitude. Since such changes of altitude and attitude are generally believed to have been accomplished slowly, the interval must be believed to have been of considerable duration.

It is true that continental altitudes and attitudes might change during a single epoch of glaciation. If the change thus brought about resulted in increased slope, the more sluggish drainage of the earlier part of the epoch would be gradually transformed into the more vigorous drainage of the later part. In this case, if the evidence of both the earlier sluggish drainage and of the later vigorous drainage remain, there should also remain the evidence of the intermediate stages. If the deposits representing the intermediate condition of drainage do not exist, while those representing both extremes do, there would be the best of reason for believing that the intermediate phases of drainage did not exist during a glacial epoch, but during an interglacial epoch, when streams were not handling glacial debris, and when they were eroding rather than depositing. The deposits of the slow and of the swift drainage might occur in such relations as to prove, beyond peradventure, that intermediate stages of *glacial* drainage never existed.

If the sluggish drainage accompanied the maximum ice invasion, while the vigorous accompanied a lesser, the evidence of the swift streams might be found far north of the southern limit of the earlier drift. The farther north of the outer border of the older drift the gravel representing the vigorous drainage of the later and minor ice-sheet occurs, the further the ice must have retreated before the change from the one type of drainage

to the other was effected. On the other hand, the farther no of the limit of the later ice advance the sluggish drainage acco panying the earlier ice-sheet may be traced, the farther mı the ice have receded before the changes resulting in vigor drainage occurred. Under certain relations, the retreat of ı ice might be shown to have been great enough, before ı orographic movements which altered the nature of the draina to constitute in our judgment, a re-advance a distinct ice epo If for example throughout the course of a long river whose ba was largely covered with ice, there be evidence that slugg drainage obtained during the maximum ice advance, and dur all stages of the ice retreat until the basin was free from ice, a if there be evidence of a vigorous glacial drainage in the sa valley at a later time, with no gradations between the two ty we have proof positive of at least a great recession, and c considerable elevation of the land after the ice had rece beyond the limits of the drainage basin and before it ag reached it in its re-advance. We hold that these phases glacial drainage deposits may be so related to each other, to valleys in which they occur, and to more or less distinct bo of glacier drift, as to prove so great a recession of ice betv the diverse phases of drainage deposition, as to constitute second advance a distinct ice epoch.

The absence of evidence that the land stood at diffe elevations during different parts of the period of drift de tion, does not in any way militate against the theory of re rent and distinct ice epochs. A constant attitude of the la the thing to be assumed, until positive evidence to the con is adduced.

(12) *Vigor and Sluggishness of Ice Action.* If it can be sl that during one epoch of glaciation, we will say the epoch of n mum ice extension, the ice action was relatively sluggish, during a later and minor advance its action was vigorous difference of action might be regarded as presumptive evic of distinct ice epochs. Evidence of the two phases of ice a here referred to are difficult of definition, but they have

independently noted by more than one glacialist. It is true that a forward oscillation of the ice edge might be more forceful than an earlier forward movement which might have reached a greater extension. In itself, therefore, this line of evidence can not be regarded as possessing great value.

It has been indicated that under certain circumstances, and in certain relations, some of the foregoing criteria, taken singly, may be conclusive of glaciations so distinct from each other, as to make their reference to separate epochs proper. But where the facts and relations which constitute one of the criteria are found, the facts and relations constituting one or more of the others are likely to be found as well. Where two of the foregoing criteria are found to be coexistent, their joint force is greater than that of either one. If neither one be absolutely conclusive, the two may still be, since the one may exactly meet the deficiency of the other. If three or more concurrent lines of evidence exist in any locality, the case is still further strengthened. We maintain that several of the foregoing criteria may be so related to each other and to the formations concerned, as not only to make the recognition of separate ice epochs proper, but to make the failure of such recognition altogether unscientific. Even when a single line of evidence, or when double, or triple, or quadruple lines of evidence are not absolutely conclusive in ruling out every conceivable technical escape from the conclusion that there were separate ice epochs, their cumulative and corroborative force may still be such as to carry conviction scarcely less positive than that which mathematical demonstration would afford. In the nature of the case not all of these various lines of evidence could be expected to be found in any one locality, or perhaps in any one limited geographic area, but where one occurs, some or all of the others are liable to be found under favoring circumstance. The number of criteria, and the great extent of area where they may hope for application, afford great possibilities.

From the foregoing discussion, it will be readily seen that the nature of the criteria and the limitations imposed upon their

application by the difficulty of proving stratigraphic continui in such a formation as the drift, necessitate the greatest care their use, and reduce the value of hasty and inexpert conclusio to a minimum.

IV. Areas Where the Criteria find Readiest Applicatic

The foregoing criteria find their readiest application regions where a later sheet of drift, suspected of belonging tc later ice epoch, failed to reach the border of an earlier sheet drift, suspected of belonging to an earlier ice epoch. The 1 2d, 3d, 4th, 5th and 10th as enumerated above, find their apr cation wholly within the area affected by the drift of the sej rate epochs, if such there were. While within this general a: they may be looked for at any point, they are likely to be rare occurrence, except along a somewhat narrow belt, say to 100 miles, adjacent to the border of the lesser ice advan The conditions for their occurrence and detection are grea favored if the lesser drift sheet be the later. The 6th, 7th, and 12th criteria might hope for application within the sa belt, but especially along a narrow zone on either side of margin of the later drift sheet. It is along this zone that types of surface are thrown into sharpest contrast, both a: material and topography. The 8th and 11th criteria have wider limits of application, both within and without the bo: of the lesser ice advance.

ROLLIN D. SALISBUR

EDITORIALS.

IT is the chief function of the national, state and provincial geological surveys to bring forth the great concrete facts relative to the structure and resources of their several fields. Within their special domains they also do an important work in the correlation of structures and formations, in the systematic aggregation of the facts, in the organizing of results, and in the development of the fundamental principles of geological science. To some extent they are permitted to do this beyond their own fields, but in the main the boundaries of these fields are the limits of their coördinations. They therefore leave a great function to be performed by some other agency in the coördination of interstate, international, and intercontinental factors. They are also restrained by their relationships to a somewhat too narrowly utilitarian public from devoting much direct attention to the solution of the deeper and broader problems that constitute the soul of science, though their contributions bear upon these in the most radical and important way. In the primary work of systematic observation, and the development of the immediate conclusions that spring therefrom, these surveys surpass all other agencies in the value of their contributions to the growth of the science, but in the secondary and ulterior work of correlation, in the synthetic aggregation and organization of results, and in the analytical and philosophical treatment of the whole, they need to be supplemented by agencies whose facilities and limitations lie in other lines, agencies whose relations and dependencies are complementary in nature. This secondary and ulterior work, in some degree, has been done by individual master students of systematic and philosophical geology, but to a very great extent it has not been done at all. It is a function which properly falls to universities, if the universities can only rise to

meet it; for it is the function of universities, in the larger mod view, not only to rehearse science, nor merely even to educ young geologists, important as that is, but to develop science science's own sake, and for its own inherent and perman utilities as distinguished from its immediate applicabilities. fulfill this function they must not only realize and appreciate but they must be equipped for field and experimental work, well as library and laboratory study. Ideal correlations a academic systematizing are as apt to be hindrances as helps the progress of science. While a few of the great universit of this country and Europe have made notable advances in th directions, the universities are, on the whole, far behind great surveys in the performance of the work which prope falls to them. This is due not so much to a lack of appreciat of the function as to the lack of facilities.

With the development of this higher function of the uni sities there goes a coördinate function for a university jou of geology, a journal whose special efforts shall be devote promoting the growth of systematic, philosophical, and fu mental geology, and to the education of professional geolog No part of the wide domain can wisely be neglected by journal, but there seems to be an open field for a perio which specially invites the discussion of systematic and fu mental themes, and of international and intercontinental tions, and which in particular seeks to promote the stud geographic and continental evolution, orographic movem volcanic coördinations and consanguinities, biological dev ments and migrations, climatic changes, and similar questio wide and fundamental interest. This field is not likely t successfully cultivated except by a systematic endeavor, pu through a period of years, to bring together the latest and summations of the results attained in the several national in a common medium, where they can be compared an cussed, and where tentative correlations will suggest thems out of which, in turn, working hypotheses will naturally s leading on to such direct investigations as the nature of

question invites. It would be presumptuous to assume that the JOURNAL OF GEOLOGY can cultivate with more than very partial success this field, but it especially invites contributions of this class.

Another phase of geology which is thought to stand in much need of active cultivation is found in the clear and sharp analysis of its processes, the exhaustive classification of its phenomena, especially on genetic bases, the development of criteria of discrimination, the more complete evolution and formulation of its principles and the development of its working methods. The recent opening of new fields of research and the rapid progress of several new and important departments of the science give peculiar emphasis to this need. The rising generation of geologists, the hope of the science, should be schooled in these latest and most critical aspects of the science. A department of the JOURNAL, entitled "Studies for Students," has been opened for the special cultivation of this field and for its adaptation to advanced students and progressive teachers of geology. Mere elementary presentations of processes and principles are not desired, but searching and critical expositions are solicited suited to the needs of young geologists who seek the highest professional equipment, and to progressive teachers who desire the fullest practicable command of the newest developments of the subject. These contributions may not be without their value to those who have already borne a considerable part of the heat and burden of life's professional day.

It is our desire to open the pages of the JOURNAL as broadly as a due regard for merit will permit, and to free it as much as possible from local and institutional aspects. It will have the very important advantage of being published under the auspices and guarantee of the University of Chicago, and will be free from the usual financial embarrassments attending the publication of a scientific magazine. This necessarily imposes upon the local editors the immediate responsibility for its editorship. Beyond this, it is hoped that its institutional relationship will disappear entirely in an earnest effort to promote the widest

interests of the science. As an earnest of this wider effo several eminent geologists, representing some of the leadir universities of this country, and some of the great geologic organizations of Europe, have kindly consented to act as assoc ate editors. T. C. C.

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UPON invitation of the World's Congress Auxiliary of t World's Columbian Exposition committees were appointed l the several sections of the American Association for the A vancement of Science at its Rochester meeting to coöperate wi it in completing the organization of scientific congresses to held at Chicago in connection with the forthcoming Worl Fair. The committee appointed by the geological and ge graphical section consisted of Thomas C. Chamberlin, John Branner, Grove K. Gilbert, W. J. McGee, Rollin D. Salisbu Eugene A. Smith, Charles D. Walcott, J. F. Whiteaves, Geo. Williams, H. S. Williams and N. H. Winchell.

It has been arranged that this committee should underta the work of preparing the scientific program for the Geologi Congress. The committee have prepared a provisional sched of topics, which they have submitted to the Advisory Cour for revision. It has seemed to the committee that all con butions should be such as to have an international inter Preferably, they should be subjects that can only be treated m advantageously in such a congress, especially those that invo the bringing together of data from different lands for comparis The committee suggest the organization of the subjects un the following general classes :

FIRST. Such as shall show the present state of geolog progress. It is believed that this can best be done by an ex bition of geological maps which shall show the latest and t results of official and other surveys. As such maps will be p pared, it is hoped, for the World's Fair, duplicates can be m at a slight expense for the use of the Congress. It is ho that each country that has made any notable progress in m

ping its geological formations will furnish for the Congress at least a general geological map, if not also special or analytical maps.

SECOND. Such subjects as bear upon continental growth and intercontinental relations. It is proposed to make this a leading line of discussion during the Congress, in the belief that there is no subject more appropriate, and that there is none which better represents the present efforts of geologists or commands a more general interest. It is hoped that analytical maps will be prepared by the geologists of the several countries representing the stages of growth of these regions in each of the great eras from the Archean to the Pleistocene, and that such analytical maps may constitute a leading feature of the several presentations. Among the subjects upon which contributions are specially invited are the following: The correlation of continental and intercontinental orographic movements and geographic accretions by sedimentation; The coördination of periods of vulcanism in the different countries; The coördination of climatic states and changes; The correlation of faunal and floral variations and migrations. It is hoped that one session may be devoted to such coördination papers bearing upon each of the great subdivisions: viz., Archean, Paleozoic, Mesozoic, Cenozoic, and Pleistocene.

THIRD. Papers on Paleontological and Archeological Geology of international scope.

FOURTH. Contributions to Physical, Structural and Petrological Geology having international or general bearings.

FIFTH. Contributions to Economic Geology having general bearings.

SIXTH. Miscellaneous papers of especial and general interest.

The foregoing groups are intended to embrace and coördinate the list of special themes announced in the circular issued by the local committee some months since, except such as may be best suited to popular presentation, for which special provision is to be made.

It will be determined later, when the number and nature of the papers are ascertained, whether all will be arranged so as to

form a continuous program, or whether sub-sections will b formed and two or more sessions held simultaneously.

It is the desire of the World's Congress Auxiliary that a fe addresses of a popular nature shall be given, with a view t stimulating an interest in the development of the science on th part of the public.

T. C. C.

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EXTRA copies of the articles appearing under the head Studies for Students will be printed and kept on sale for the u of teachers and advanced classes. The prices will be fixed low as practicable, and a standing list published in the advert ing columns of the JOURNAL.

REVIEWS.

On the Glacial Succession in Europe. By Prof. JAMES GEIKIE. Transactions of the Royal Society of Edinburgh, Vol. XXXVII., Part I. (No. 9), 1892, pp. 127–149 (with a map).

IN this timely essay Prof. Geikie reaches the following conclusions:

1. The record of the first glacial epoch is found in the Weyborn Crag of Britain, and the ground moraine beneath the "Lower Diluvium" of the continent. During this epoch, the direction of the ice movement in southern Sweden was from the south-east to the north-west. This first glacial epoch of which direct evidence is adduced was followed by an interglacial interval, during which the forest-bed of Cromer, the breccia of Hötting, the lignites of Leffe and Pianico, and certain beds in central France were deposited. During this interglacial epoch, the climate is believed to have been very mild.

2. There followed a second epoch of glaciation, when the ice sheet of Britain became confluent with that of the continent. This was the epoch during which the ice sheet reached its southernmost extension. Its depositions are found in the lower boulder clays of Britain, the lower diluvium of Scandinavia and north Germany (in part), the lower glacial deposits of south Germany and central Russia, the ground moraines and high level gravel terraces of Alpine lands, and the terminal moraines of the outer zone. During this second glacial epoch, Alpine glaciers are believed to have attained their greatest development. This epoch of extreme glaciation was followed by an interglacial interval, during which Britain is believed to have been joined to the continent. During this interval, the climate became temperate. In Russia (near Moscow) there seems to be evidence that it was milder and more humid than that of the same region at the present day. Toward the close of the mild epoch, submergence seems to have been accompanied by an increasing degree of cold, which finally ended in another glacial epoch.

3. The subsidence which marked the close of the second interglacial interval, marked likewise the inauguration of the third glacial

epoch. Its work is represented in Britain by the upper boulder cla in Scandinavia and Germany by the lower diluvium (in part), in centr Russia by the upper glacial series, in Alpine lands by ground moraine and gravel terraces. The ice sheets of Scandinavia and Britain we again confluent, but did not extend quite so far south as during th second glacial epoch. This third glacial epoch is believed to hav been followed by another interglacial interval, during which fresh wat alluvia, lignite and peat accumulations were made. These are repr sented by the interglacial beds of north Germany, and by some the so-called postglacial alluvia of Britain. There were also mari deposits on the coasts of Britain and on the borders of the Balti During this interglacial interval, Britain is believed to have been co tinental. The climate was temperate, but in the course of time becar more severe. This increasing severity seems to have been accomp nied by submergence, which amounted to something like 100 ft. bel the present sea-level on the coasts of Scotland. The Baltic provin of Germany were also invaded by the waters of the North Sea.

4. There followed a fourth period of glaciation, during whi the major part of the Scottish Highland was covered by an ice she Local ice sheets existed in the southern uplands of Scotland and mountain districts in other parts of Britain, and the great val glaciers sometimes coalesced on the low lands. Icebergs floated at the mouths of some of the highland sea-lochs. In some pla terminal moraines were deposited upon marine beds which were tl in process of formation. These beds are now 100 ft. above the level. At this time Scandinavia was covered by a great ice sh which yielded icebergs to the sea along the whole west coast of N way. The ground moraines and terminal moraines of the mount regions of Britain represent the deposits of this ice epoch. upper diluvium of Scandinavia, Finland, and north Germany re sent the work of the contemporaneous, but not confluent, ice shee the continent. In the Alps, terminal moraines in the large lo tudinal valleys were made at the same time.

This fourth glacial epoch was followed by a fourth intergla interval, during which fresh water alluvial deposits were made, also the "lower buried forest and peat" of Britain and no western Europe. At this time, Scotland seems to have stood 4 50 feet lower than now, and Carse clays and raised beaches repre the work of the sea. During this interglacial interval, Britai

believed to have become again continental, while the climate became so far ameliorated as to allow the growth of great forests. Subsequently the insulation of Britain was effected, and this was followed by a climate which was probably colder than the present.

5. The severity of the climate which marked the close of the fourth interglacial interval was such as to bring about local glaciation in some of the mountain valleys of Britain. Here and there the glaciers projected their moraines so far down the mountains that they rest on what is now the 45 to 50 feet beach. In the Alps, this fifth epoch of glaciation is represented by the so-called postglacial moraines in the upper valleys. This is believed to have been the last appearance of glaciers in Britain. The dissolution of these glaciers was again followed by an emergence of the island, and by more genial climatic conditions.

In support of his conclusions, Prof. Geikie cites some striking facts which are not so widely known as they should be. For example, Swedish geologists have found evidences that there was an ice sheet antedating that which deposited the "lower diluvium," and that during this earlier glaciation the direction of ice movement in southern Sweden was from the south-east to the north-west. The ground moraine deposited by this ice sheet is overlain by the "lower diluvium" which was produced by an ice movement from the north north-east to the south south-west, or nearly at right angles to the first. Again, near Moscow, there exist interglacial beds whose plant remains indicate a climate milder and more humid than that of the present time. These interglacial beds, it will be observed, occur in the region of the "lower diluvium" quite beyond the margin of the ice which produced the "upper diluvium" of Germany and Scandinavia. During this interglacial interval, Prof. Geikie maintains that no part of Russia could have been covered with ice. If, then, within the limits of the area covered by the "lower diluvium," and not by the "upper," distinct beds of glacial drift are separated by such beds as those cited, there can be no question but that such separation marks two distinct glacial epochs. If there was an earlier glaciation when the movement of the ice in Sweden was at right angles to that during which the lower part of the "lower diluvium" was produced, this also would seem to be good evidence of three ice epochs prior to the "upper diluvium." The epoch of the "upper diluvium" would then constitute the fourth glacial epoch, and this is the interpretation of Prof. Geikie.

Outside the area of the European continental ice sheet, facts a adduced in striking confirmation of the multiple ice epoch theo These facts are found in Switzerland, where evidences of multip glaciation have been recognized, and in the Pyrenees where evidenc of three separate ice epochs have been found. In France, evidenc of an inter-glacial interval have been found in the region of the P de Dôme of such duration as to allow the excavation of valleys to depth of 900 feet. The length of time which would be required f such stupendous erosion must certainly be regarded as sufficient allow the preceding and succeeding glaciations to be considered belonging to two distinct epochs.

Another point of great significance and interest which Pr Geikie's essay brings out, is the correlation in Britain between epo of glaciation and epochs of subsidence on the one hand, a between interglacial intervals and epochs of elevation on the ot If Prof. Geikie's interpretation be well founded, and so far as we able to judge from the facts presented this is the case, his conclusi would seem to be fatal to the hypothesis that glacial climate was p duced by northern elevation.

The map which Prof. Geikie gives, showing the limit of advance during the fourth glacial epoch, seems to us open to critici On the ground of personal observation, the writer believes that the sheet of the glacial epoch here represented did not extend notably at all, beyond the Baltic Ridge.[1]

Prof. Geikie is an advocate of Dr. Croll's astronomical theor glacial climate, and thinks that even five is not the full numbe glacial epochs belonging to the Pleistocene period. He believes t may have been a series of glacial epochs increasing in severity to a m mum represented by what is now designated as the second glacial ep This maximum was followed by a series of epochs of diminishing seve represented by what he designates the third, fourth and fifth epochs. essay is a timely contribution to glacial geology. ROLLIN D. SALISB

[1] See *American Journal of Science*, May, 1887. In a recent letter, Prof. C indicates that he is convinced, from subsequent personal observation, that his m erroneous so far as the limit of the ice of this epoch is concerned. The ma given was based on the opinion of others.

Analytical Abstracts of Current Literature.[1]

The Sub-Glacial Origin of Certain Eskers. By WILLIAM MORRIS DAVIS, Harvard University. (Proceedings of the Boston Society of Natural History, Vol. XXV., May 18, 1892).

A critical discussion of the conditions under which it is conceived certain eskers and sand plateaus (plains) were formed. The Auburndale district, ten miles east of Boston, presents three classes of modified drift deposits;—sand plateaus, eskers, and kames. These deposits are well exposed.

The sand plateaus have the characteristics of delta deposits of glacial streams,—even surfaces, well-bedded sands and gravels, the beds sloping outward from the "head" at an angle of 12° to 20°, and in close agreement with the slope of the plateau front, a lobate margin, deposits distinctly coarser at the head than near the front, and a series of nearly horizontal roughly cross-bedded gravels overlying the sloping beds.

The eskers are essentially of the same material as that of the plateau, often so poorly stratified as to render differentiation of the beds difficult. The interstices between the pebbles are often unfilled, although there is abundance of fine material in adjoining layers. This "open work" is taken to indicate rapid deposition, and seems to preclude the supposition that the gravels have settled down from a superglacial position, or been traversed by currents of any volume. In several instances the eskers can be followed to direct union with sand plateaus. Towards its lower end the esker frequently "gives out branches" and "the adjacent lowland surface becomes more or less encumbered with sand mounds or kames," indicating a decayed margin of the ice.

Prof. Davis' conclusions are:

"1. The eskers and sand plateaus of Auburndale and Newtonville were formed by running water just inside and outside of the ice margin in the closing stage of the last glacial epoch.

"2. The ice-sheet was a stagnant, decaying mass at the time of their formation, as is shown by the ragged outline of its margin.

[1] Abstracts in this number are prepared by Henry B. Kummel, Chas. E. Peet, J. A. Bownocker.

"3. Eskers and sand plateaus are genetically connected; the term, feeding-esker, is fully warranted by the relation of the two in position, structure and composition.

"4. The sand plateaus were made rapidly; this is proved by the absence of disordered beds at their heads, where space would have been opened by the backward melting of the ice had the forward growth of the plateau been slow The eskers were also made rapidly, as is shown by their 'open-work gravels.

"5. The diversion of the feeding streams to other outlets left the plateaus and the eskers without further energetic action as the ice melted away from them

"6. The present form and structure of the eskers are more accordan with the supposition of a subglacial origin than of a superglacial origin; bu it is not intended to imply that other eskers of more irregular form and dil ferent structure could not have been deposited in superglacial channels."

H. B. K.

Studies in Structural Geology. By BAILEY WILLIS, U. S. Geol. Sur (Transactions of the American Institute of Mining Engineer June, 1892).

The paper aims "to present some of the results of observation of th geologists of the Appalachian division during the past three years on th subject of structural geology in the Appalachian province." The structur features are all of one type but of different phases, comprised in four gre districts. 1) the district of close folding, 2) a district whose chief structur characteristic is cleavage, 3) a district of open folding, 4) a district of fau ing and folding. The answer to the questions, Why did the strata bend the district of open folding, and why did they break in the district of fau ing, is that the thrust affected them according to their rigidity under th respective conditions of superincumbent load. "We know that load up a certain point restrains fracture in material under thrust." In the distr of open folding the Devonian limestone is the most rigid of the strata a "the one which would most effectively transmit the compressing thrust a would control the resulting structure." In the district of open folding t limestone was prevented from breaking and faulting by a load of super cumbent strata exerting a pressure of 10,000 to 23,000 pounds per squ inch, while in the faulted district a load of 5,000 to 10,000 pounds per squ inch permitted the strata to break and fault.

The answer to the question, Why did the compression affect this zone given. "It becomes apparent on study of sections that where compress raised a great arch there previously existed a bend from a nearly horizor to a descending position in the principal stratum transmitting the thr Greater anticlines and synclines originated in upward and downward c vexity of initial dips, due to unequal deposits of sediments which dep

underlying strata in proportion to their weight. Such folds may be called original." The Pottsville, Mahanoy, Shamokin and Wyoming coal basins of Pennsylvania belong to this class.

Experiments have recently been carried on in the office of the United States Geological Survey reproducing the different forms of folding. The experiments differed from other experiments in that 1) the materials used to simulate the stratified rocks varied in consistency from brittle to plastic, according to the depth at which deformation is supposed to take place; 2) the compression was exerted under a movable load representing the weight of superincumbent strata; 3) the strata rested on a yielding base to simulate the condition of support of any arc of the earth's crust. The following are the conclusions from the experiments:

1. "When a thrust tangentially affects a stratified mass, it is transmitted in the direction of the strata, and by each stratum according to its inflexibility. At any bend the force is resolved into components, one radial, the other tangential to the dip beyond the bend; the radial component, if directed downward, tends to depress the stratum and displace its support.

2. "A thrust so resolved can only raise an anticline or arch which is strong enough to sustain the load lifted by its development; such an arch may be called competent; and since strength is a function of the proportions of a structure, it follows that, for a given stratum, the size of a competent anticline will vary inversely as the load; or for a given load the size will vary as the thickness of the effective stratum.

3. "The superincumbent load borne by a competent anticline is transferred to the supports of the arch at the points of inflection of the limbs.

4. "When a competent arch is raised by thrust from one side, the load transferred may so depress the resulting syncline further from the force that an initial dip will be produced in otherwise undisturbed strata; this dip will rise to a bend from which a new anticline may be developed. This anticline is a result of the first, and may be called 'subsequent' in distinction to original folds. Since subsequent folds are simply competent structures, their size will be determined by conditions of thickness and load, and for like conditions they should be equal; and they must, in consequence of conditions of development, be parallel to the original fold and to each other. An example of an original fold with its subsequent anticlines is the Nittany arch and the group of parallel anticlines which lie southeast of it, extending northeast from the Broad Top basin."

C. E. P.

The Catskill Delta in the Post-Glacial Hudson Estuary. By WILLIAM MORRIS DAVIS. (From the Proceedings of the Boston Society of Natural History, Vol. XXV., 1891).

The post-Tertiary trenches of the Hudson and its tributaries are in the main filled with clay beds, which, covered by a thin deposit of sand, rise in

terraces 130, 150, or even 180 feet above tide-water. These clays are the result of a late glacial or postglacial submergence of the valley, but their upper surface does not indicate the amount of their submergence, as they are bottom deposits Delta deposits made by the tributary streams, where they entered the Hudson estuary, would indicate the amount of submergence.

Such deposits are found on the Catskill a mile north of Cairo, and eroded remnants are traceable for three or four miles down stream. The surface is characterized by great numbers of water-worn stones up to fifteen or eighteen inches in diameter. The lobate margin, where present, is poorly defined. These deposits range from 290 feet (aneroid) above tide, up river, to 270 feet further down. One-tenth of a cubic mile of material seems to have been washed into the Catskill trench at the point of this delta between the time of the ice departure and the elevation of the land. Subsequent terracing has removed half that amount.

The course of the Catskill at Leeds, where it crosses a ledge of hard Corniferous limestone is probably of postglacial superimposed origin, but the preglacial valley cannot be definitely fixed. H. B. K.

Geological Survey of Alabama.—Bulletin 4. By C. WILLARD HAYES. (Report of the Geology of Northeastern Alabama and Adjacent Portions of Georgia and Tennessee).

This report covers an area of 5950 miles, two-thirds in Alabama. Topographically it falls into three divisions: 1) the Cumberland and other plateaus of the northwest; 2) in the center, anticlinal valleys — Browns and Wills, with the synclinal mountains — Sand and Lookout; 3) the monoclinal mountains, the "flatwoods" (Coosa shales) and the chert hills (Knox limestone) of the southeast. The drainage of the first is radial from the center of the plateau to the Tennessee; that of the second, once consequent upon the folded structure, is now adjusted to the strike of the soft beds.

The formations are Cambrian, Silurian, Devonian and Carboniferous. Total thickness is from 13,000 to 18,000 feet in the east, but decreases westward. Hard sandstones of the Carboniferous form the cappings of the plateaus and synclinal mountains. In the anticlinal and monoclinal valleys the Silurian and Cambrian appear. The rocks pass from the nearly horizontal beds of the plateau region, by narrow unsymmetrical anticlines with steeper dip on the northwest side, and by broad shallow synclines, to the complicated folds of the southeast. The axes of these latter folds dip more or less abruptly northward and southward, causing the ridges to assume zigzag courses. Synclines are often crossed by anticlines.

Thrust faults exist, some of great magnitude, and traceable for 200 to 300 miles. By the "Rome thrust fault" the Cambrian shales have been shoved four to five miles over upon the Carboniferous shales. Most of the over-

thrust strata have been worn away, but tongues of Cambrian shale still remain to all appearances lying conformably upon the Carboniferous strata. Transverse thrust faults terminate Gaylor's ridge, Dirt Seller Mountain, and Lookout Mountain on the south. H. B. K.

The Correlation of Moraines with Raised Beaches of Lake Erie. By FRANK LEVERETT, U. S. Geol. Surv. (Wisconsin Academy of Science. Vol. VIII., 1891).

References have been made in Geological literature to the beaches of the eastern portion of the Lake Erie basin, but up to the time of Mr. Leverett's work none of the beaches had been completely traced. Mr. Gilbert had discovered that several of the raised beaches do not completely encircle Lake Erie, and supposed that their eastern termini represent the successive positions of the front of the continental glacier during its retreat northeastward across the Lake Erie basin. Mr. Leverett verifies this theory by demonstrating that certain moraines are the correlatives of the beaches. They are as follows:

I. The Van Wert or upper beach and its correlative moraine, the Blanchard ridge. II. The Leipsic or second beach and its correlative moraines. III. The Belmore, or third beach and its correlative moraine.

I. The Van Wert beach extends eastward from the former southwestward outlet of Lake Erie near Fort Wayne, Indiana, to Findlay, Ohio, where it joins the Blanchard moraine. Through Indiana and Ohio its altitude is quite uniformly 210 feet above Lake Erie.

While the Van Wert beach was forming, the ice front was the northeastern shore of the lake as far east as Findlay, Ohio, its position being marked by the Blanchard moraine. East of Findlay, where the Van Wert beach joins it, the moraine is of the normal type. But west of Findlay, it presents peculiarities of topography and structure, resulting from the presence of lake water beneath the ice margin. The water was shallow and incapable of buoying up the ice-sheet, and producing icebergs. The motion of the water under the ice-sheet produced a variable structure. This is the only instance of a moraine demonstrably formed in lake water.

II. The Leipsic, or second beach, was formed after the ice had retreated from its position marked by the Blanchard moraine. Its altitude is 195 to 200 feet above Lake Erie. It has its terminus near Cleveland, where it connects with the western end of a moraine.

III. The Belmore beach and its correlative moraine. Between the Leipsic beach and the present shore of Lake Erie are several beaches. One of these, the Belmore beach, terminates near Cleveland, while the others extend into southwestern New York, and probably connect with moraines, though this connection has not been traced. The general altitude of the Belmore beach in Ohio is 160 to 170 feet above Lake Erie. Unlike the Van Wert and

Leipsic beaches, it does not directly connect with a moraine at its eastern en but a gap of ten miles intervenes. Terraces at Cleveland, Mr. Levere thinks, make a connection between the eastern end of the beach and the wes ern end of the moraine at Euclid, Ohio. C. E. P.

The Climate of Europe During the Glacial Epoch. By CLEMENT REI (Natural Science. Vol. I, No. 6, 1892).

Temperature of the Sea.—The temperature of the English Channel w similar to that where the isotherm of 32° F. is now situated. The wint temperature can scarcely have been 20° colder than at present. The Med terranean was perhaps 5° colder than now.

Temperature of the Land (air).—It does not appear that the climate the lowlands of southern Europe can have been 20° lower than the prese mean; 10° or perhaps less appear to have been the refrigeration in the Me iterranean region. The temperature at the southern margin of tl ice-sheet was about 20° colder than at present. The temperature increas rapidly towards the south. Recent observations seem to show that throug out central Europe there was a period of *dry* cold, causing the country resemble the arid regions of central Asia. J. A. B.

On the Glacial Period and the Earth-Movement Hypothesis. By JAM GEIKIE, Edinburgh, Scotland. (Read before the Victoria Institu London).

Geologists generally admit that there have been at least two gla epochs, separated by one well-marked interglacial period. The clos stage of the Pleistocene period was one of cold conditions in no western Europe, accompanied by land depressions. After this came a ge climate with a union of the British islands among themselves and also v the continent. This was followed by a cold, humid condition.

Upham maintains that the whole of North America north of the Gul Mexico stood at least three thousand feet higher at the beginning of glacial epoch than at present. Fiords were formed before glacial times so can not be cited as evidence of high land during the glacial period. elevation of land in the northern part of North America and Europe c not produce glaciation in their southern parts. The deflection of the Stream by the sinking of the Panama, Professor Giekie argues, could produce the conditions which prevailed during the glacial epoch. Earth-Movement hypothesis, he believes, accounts neither for the widesp phenomena of the ice-age, nor for the remarkable interglacial clim Some maintain that the warm interglacial period was produced by the of the Panama land, the sinking of the lands to the north, and the turni the Gulf Stream from the Pacific into the Atlantic. Why then, asks Pr sor Geikie, do we not have such a climate now? J. A.

ACKNOWLEDGMENTS.

The following papers have been donated to the library of the Geological Department of the University of Chicago, mainly by their authors:

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HURONIAN

Ah The Original Huronian
Ah 2 The Marquette Menominee
Ah 3 The Wisconsin Valley Slates
Ah 4 The Penokee Iron Bearing
Ah 5 The St. Louis Slates
Ah 6 The Chippewa Valley Quartz...
Ah 7 The Black River Iron Bear...
Ah 8 The Baraboo Quartzites
Ah 9 The Sioux Quartzites
Ah 10 The Animikie Series
Ah 11 Folded Schists of Canada

THE

JOURNAL OF GEOLOGY

FEBRUARY-MARCH, 1893.

AN HISTORICAL SKETCH OF THE LAKE SUPERIOR REGION TO CAMBRIAN TIME.[1]

(WITH PLATE I.)

THE ancient formations south of Lake Superior may be grouped into five great divisions: the Basement Complex, the Lower Huronian, the Upper Huronian, the Keweenawan, and the Lake Superior Sandstone. These five divisions are separated by unconformities of great magnitude, two of them at least being of the first order. According to the classification adopted by the United States Geological Survey, the Basement Complex is Archean; the Lower Huronian, Upper Huronian and Keweenawan constitute the Algonkian for this region; and the Lake Superior Sandstone is Cambrian.

The Basement Complex.—The characteristic rocks of the Basement Complex are (1) light colored granites and gneissoid granites, and (2) dark colored finely foliated or banded gneisses or schists. These are cut by various basic and acid intrusives, many of which are not different from eruptives

[1]In this very general article no attempt will be made to give references to the many authors from whom facts are taken. To give full credit for all information used would require citations from scores of papers. The writer gives a summary of the literature of the Lake Superior Region in Bulletin 86 of the U. S. Geol. Survey.

Many of the problems considered have no definite answers as yet. The aim of the article is to give a summary of the very limited knowledge available on a subject that has not before been considered, because the data were not at hand upon which to base any reliable conclusions.

found in the later series, with which they are doubtless in part continuous.

The granites and gneissoid granites are placed together, because between the two are constant gradations. If one speaks accurately and includes among granites only those rocks which are completely massive, the gneissoid granites include the greater part of the granitic rocks; for in large exposures it is usually possible to find some evidence of foliation. The granitoid areas are of greatly varying sizes, running from small patches to those many miles in diameter. When everywhere surrounded by the schistose division of the Basement Complex, they frequently have oval or ovoid forms. In nearing the outer border of the granitoid areas, the foliation often becomes more and more prominent, and near the edge of an area the rock frequently passes into a well laminated gneiss.

The schistose rocks include fine grained hornblende-gneisses, mica-gneisses, chlorite-gneisses, and various green schists, formerly supposed to be sedimentary, but now known to be greatly modified basic and acid igneous rocks. These schists have usually a dark green or black color, are strongly foliated, and the variations in strike and dip of this foliation, within small areas, is very great. Not infrequently the schistose rocks are traced by gradations into massive igneous rocks.

The contacts between the schistose division and the granitoid division of the Basement Complex are usually those of intrusion, the granitoid rocks being the later. In passing from a schistose to a granitoid area, small pegmatitic looking veins of the granite are first found. In going onward these veins become more numerous and, after a time, unmistakable dikes of granite appear, which multiply in number and size in approaching the granite area, until the granite is found in great bosses. Here we have perhaps a nearly equal quantity of schistose and granitoid rocks, and in this intermediate zone the schists may be found as a mass of blocks within the granite, sometimes at but small distances from their original positions, the whole having frequently a somewhat conglomeratic appearance. However, these pseudo-

conglomerates, so well described by Lawson, grade more or less rapidly on the one hand into the schists, and on the other into the solid gneissoid granite. The complete change may occur within a short distance, or it may take a mile or more.

The Basement Complex is then composed of intricately interlocking areas of granitoid rocks and schistose rocks. Moreover, all of these rocks are completely crystalline. None of them show any unmistakable evidence of having been derived from sedimentaries, but many can be traced with gradations into massive rocks, and therefore the greater proportion of them are igneous, if a completely massive granular structure be proof of such an origin.

The Basement Complex is the most widespread of any of the Lake Superior systems, and it doubtless runs under all later formations to a greater or lesser distance. That it is continuous under all such formations can not be asserted, for while it was once so, it is possible, perhaps even probable, that in places, as a consequence of sedimentation and folding, the Basement Complex has been so deeply buried, that fusion has locally resulted. It is even possible that such fused material is a partial source of the later volcanic eruptions.

Before the earliest sedimentary rocks were deposited, the Basement Complex was subjected to enormous orographic forces, which folded and sheared the rocks in a most intricate manner. Accompanying the great orographic movements, which undoubtedly occupied a vast period of time, were intrusions of various deep seated igneous rocks, and also doubtless their volcanic equivalents were extruded. Subsequent to, and during the orographic movements, atmospheric forces were at work. Erosion continued long after the mountain-making folding had ceased, and, for much of the Lake Superior region, reduced the Basement Complex nearly to a plain or base level. As evidence of this may be cited the fact that, at the end of the erosion interval, the Basement Complex, consisting of differing lithological materials, and therefore having a variable resisting power, did not vary in altitude more than a few hundred feet for long dis-

tances. Whether this denudation extended everywhere deep enough to remove all surface volcanic material, and to leave only deep seated igneous material, is undetermined. At the beginning of the Lower Huronian time, the Basement Complex was, in the Lake Superior region, a universal system.

The Lower Huronian.—After the forces of erosion had nearly exhausted themselves, there was the first advance of the sea over the Lake Superior region of which we have any evidence, as a result of which the Lower Huronian was deposited.

The well-known characteristic rocks of the Lower Huronian, are (1) conglomerates, quartzites, quartz-schists and mica-schists, (2) limestones, (3) various ferruginous schists, (4) basic and acid eruptives, which occur both as deep seated and as effusive rocks. The order given, with the exception of the eruptives, is the order of age from the base upward.

The inferior formation is usually a quartzite or a feldspathic quartzite. Where metamorphism has been severe it passes into a quartz-schist, mica-schist or gneiss. The lowest horizon of the formation is in places a coarse conglomerate, and this when metamorphosed may become a conglomerate-schist. This conglomerate is of two types, depending upon the character of the underlying formation, which is here granitic and there schistic. The limestone formation, when at its maximum, is of very considerable thickness. The limestone is magnesian and so very crystalline as to make the name marble appropriate. It frequently contains a considerable amount of chert. In places it may be divided into two horizons, one of which is nearly pure marble, and the other nearly pure chert. At other times the limestone becomes very siliceous by a mingling of fragmental quartz, while zones of wholly fragmental material may occur. These impure phases are often at the lower part of the limestones, where they may be considered as a transition from the underlying formation. The formation overlying the limestone is usually known as the iron-bearing member, since it contains all the ore bodies of the Lower Huronian. It has varied aspects, but the different varieties grade into one another both vertically and

laterally, so that when one becomes familiar with them, the rocks of the formation may invariably be recognized. Here are included hematitic and magnetitic schists, cherts, jaspers, ferruginous carbonates, and other forms. The formation always differs from the limestone in carrying a very considerable amount of iron, and it differs from the quartzite in being largely, and sometimes wholly, a chemical or organic sediment, rather than a mechanical one.

The three members of the Lower Huronian are not often seen in a single section. This may be due to lack of exposures, but in some cases is undoubtedly due to the absence of one or more of the formations themselves.

In the Lower Huronian, basic eruptive rocks are abundant, and locally cover considerable areas. Not infrequently acid eruptives also occur. These eruptives include both contemporaneous volcanics and subsequent intrusives. If the Keewatin of Lawson about Rainy Lake and the Lake of the Woods is Lower Huronian, great granitic masses have been intruded into this series northwest of Lake Superior.

Equivalent to the Lower Huronian series of the north shore of Lake Huron are placed the following iron-bearing districts: Lower Vermillion, Lower Marquette, Felch Mountain, in large part, Lower Menominee, the cherty limestone formation of the Penokee district; and probably the Kaministiquia series of Ontario, and the Black River Falls series of Wisconsin. Whether all of these detached basins were once connected by continuous sediments is unknown, but probably they were.

The fragmental material of the Lower Huronian was derived from the Basement Complex. This fragmental formation is usually thin. This doubtless means that the advance of the sea over the Lake Superior region was comparatively rapid. The directions from which the Lower Huronion sea entered, and the extent of its trangression, is at present unknown. By certain of the Canadian geologists it is held that the structural break which exists between the Basement Complex and the Lower Huronian, south of Lake Superior and north of Lake Huron, does not exist

in the region of Rainy Lake and Lake of the Woods, northwes of Lake Superior. If this conclusion be true, the sea did no advance as far as the Lake of the Woods, this district perhap being above the ocean, and one of the sources of detritus throughout Lower Huronian time.

The extent of the Lower Huronian deposits is also uncertain If the series of the districts above placed in the Lower Huronian are correctly correlated, Lower Huronian basins occurred in various places over a great triangular area extending from Blacl River Falls in Wisconsin, to northeastern Minnesota, and thenc east to the north shore of Lake Huron. Doubtless Lowe Huronian rocks also occur in the great northern region c Canada, and they may have had a much wider original exter than this, but no data are now available to locate such a possibl extension.

Of the original thickness of the Lower Huronian deposits w are also ignorant. The present thickness has not been dete mined south of Lake Superior, but according to Logan, on tl north shore of Lake Huron, including the interstratified volcanic the thickness is five thousand feet.

At the end of Lower Huronian time, the Lake Superi region was raised above the sea, folded, and subjected to erosio The orographic movements of this time were very severe, close crumpling in places the rocks of the Lower Huronian, and indu ing in them in many places a schistose structure. In other loca ties, away from the axes of great disturbance, the Low Huronian rocks were but gently tilted, as is shown by the sm discordance in places between them and the succeeding seri In certain localities the areas of great disturbance are but a sh distance from those of comparative quiet. The denudation v deep enough to wholly remove the entire series over wide are and to cut to unknown depths into the Basement Complex its As has been stated, the Lower Huronian has an estimated thi ness of about one mile on the north shore of Lake Huron, a in different localities varies from this thickness to entire absen depending mainly upon the differing deundation. This varia

ity may possibly be due in part to highlands of the Basement Complex, which were not covered by the Lower Huronian sea until the period was well advanced. Of the extent of the series at the end of the erosion preceding Upper Huronian deposition, little has been determined, since later erosions have undoubtedly removed large areas of the series, and therefore its present distribution is not a safe guide to its distribution at the close of the erosion interval referred to.

The Upper Huronian.—At the close of the long period of erosion which followed the Lower Huronian deposition, the water once more advanced upon the Lake Superior region, and the Upper Huronian series was deposited.

Lithologically this series consists of conglomerates, quartzites, graywackes, graywacke-slates, shales, mica-schists, ferruginous slates, cherts, jaspers, ferruginous schists and igneous rocks, including both lava flows and volcanic fragmentals, as well as basic and acid intrusives. The series, as a whole, is very much less crystalline than the Lower Huronian, although locally the shales and graywackes have been transformed into mica-schists, and even into gneisses.

The Upper Huronian immediately about Lake Superior is divisible into three formations, a lower slate, an iron-bearing formation, and an upper slate, the basis of separation being that of mechanical and non-mechanical detritus. The inferior formation is mainly a quartzose slate or shale, but locally it passes into a quartzite, while the basal horizon is frequently a conglomerate. The nature of this conglomerate varies greatly, depending upon the character of the underlying formation, which, in some areas, is the Basement Complex, and in others the Lower Huronian. In the first case the slates may rest upon the gneissoid granite, upon the schists, or upon the junction of the two. The basal conglomerate corresponds in its character, being a recomposed granite or granite-conglomerate, a recomposed schist or schist conglomerate, or finally a combination of the two.

When the lowest member of the Upper Huronian rests upon the Lower Huronian series, the underlying formation may be

any one of the three formations of the Lower Huronian. As a consequence the basal conglomerate may consist mainly of the fragments of any one of these formations, or of all of them together. Not infrequently detritus, derived from the Basement Complex, is mingled with that of Lower Huronian origin. However, as a consequence of the resistant character of the jaspery iron-bearing formation of the Lower Huronian and of mining operations, the discovered contacts are most frequently betweer the Upper Huronian and this iron-bearing formation. In th basal conglomerate or recomposed rock at these points, th characteristic fragments are chert, jasper, and other ferruginou materials, and it is locally so rich in iron as to bear ore-bodies The uppermost horizon of the lower slate of the Upper Huronia in the Penokee district is a pure, persistent layer of quartzite The central mass of the formation is a graywacke or graywacke slate, passing in places into a shale or sandstone.

Above the lower slate is the iron-bearing member, consistin of various ferruginous rocks, including cherts, jaspers, magnetit actinolite-schists, iron ores, and ferruginous carbonates. It h been shown that all these varieties have been mainly derive directly or indirectly by transformation from an original lea iron-bearing carbonate, which was of chemical or organic origi or a combination of both. Mingled with these non-mechanic sediments is a greater or lesser quantity of mechanical detritus

Above the iron-bearing formation is the upper slate form tion. This is mainly composed of shales frequently carbo aceous or graphitic, slates, graywackes and mica-schists, oft garnetiferous and staurolitic. The mica-schists are usual toward the upper part of the formation. The stages of t transformation between these crystalline rocks and plain fragmental detritus have been somewhat fully made out.

The lower slate formation is of variable thickness, but usually less than a thousand feet. The iron-bearing formation also of very variable thickness, its maximum being perhaps ab the same as that of the lower slate, and from this it varies to d appearance, the horizon being usually represented, however,

carbonaceous and ferruginous shales and slates. The upper slate formation includes the great mass of the Upper Huronian series. Its maximum thickness is more than ten thousand feet.

In certain areas, during Upper Huronian time, there was great volcanic activity, as a result of which, peculiar formations were piled up, wholly different from any of the ordinary members of the series. Also this volcanic activity greatly disturbed the regular succession, so that for each of the volcanic districts an independent succession exists, the sedimentary and volcanic formations being intimately interlaminated. The two areas which are best known are the Michigamme iron district north of Crystal Falls and the east end of the Penokee district. Similar volcanics also occur in the Marquette district. In the Michigamme iron district is an extensive area of greenstones, greenstone-conglomerates, agglomerates and surface lava flows, many of which are amygdaloidal. In the Penokee district the materials are almost identical. The typical succession for this district extends in unbroken order for fifty miles or more, but east of Sunday Lake this is suddenly disturbed by the appearance of the volcanics. The character of the rocks and their order soon becomes so different that if one were not able to trace the change from one into the other, there would be a great temptation to regard the part of the series bearing volcanics earlier than or later than the Penokee series proper. But the continuity of the two cannot be doubted. Thus this occurrence well illustrates that lithological character in pre-Cambrian, as in post-Cambrian time is no certain guide as to relative age. Finally, associated with the Lake Superior Upper Huronian rocks are many later intrusive dikes and interbedded sills, chiefly diabases, gabbros and diorites, but local granitic intrusives also occur, particularly in the Felch Mountain and Crystal Falls districts, and possibly also in the Menominee district.

The typical districts in which the Upper Huronian series can be best studied are the Penokee, Marquette, Mesabi and Animikie. Remote from the Lake Superior region proper, the rock series

which are correlated with the Upper Huronian have not the same successions of formations as in these districts. The Upper Huronian north of Lake Huron has a set of formations which can not be correllated with the formations above given; the same is true of other series to the south which are here placed. The position of these latter as a part of the Upper Huronian must not be considered as a question finally determined, but rather as representing the probability, from the weight of evidence at the present time. It can not be expected that in a great geological basin the same subordinate succession of formations will be everywhere found.

However, for the present, regarding all these series as Uppe Huronian, this is the most widespread of the Lake Superior pre-Cambrian sedimentary series. It includes a great area, extending from the Sioux quartzites of Dakota on the southwest, to th Huronian rocks north of Lake Huron on the east, and thence fa to the north, and from Lake Huron to the Animikie series of th National Boundary west of Lake Superior. Within this are are included the major portion of the Baraboo quartzites o Wisconsin; the major portion of the large area in the Uppe Peninsula of Michigan, the eastern arms of which are the Menom inee, Felch Mountain, and Marquette iron-bearing districts; th greater part of the Penokee-Gogebic iron-bearing series Michigan and Wisconsin; the Chippewa quartzites of Wisconsin St. Louis slates of Minnesota including the newly develope Mesabi range of Minnesota, and the Animikie series of Thund Bay, Lake Superior and its westward extension. That most, ar perhaps all of these areas were once connected, there can be reasonable doubt.

This broad semicircular zone of Upper Huronian rocks, exten ing from the National Boundary west of Lake Superior throu Ontario, Minnesota, Michigan and Wisconsin, to the nor Channel of Lake Huron, and thence north to the east side of Jam Bay, suggests that the transgression of the sea was from t south and east, and that the source of the mechanical detritus the great expanse of so-called Laurentian rocks west of Huds

Bay and north of Lake Superior. How far the sea transgressed over this area, and whether it also advanced toward it from the north and west, is unknown. It is probable as the sea advanced from the south, that the great mass of fragmental detritus, making up the Baraboo and Sioux quartzites, was laid down before the sea had transgressed to what is now the north shore of Lake Superior, and thus would be explained the discrepancy in the parallelism of formation between the Sioux quartzites, Baraboo quartzites, etc., and the districts of Upper Huronian rocks adjacent to Lake Superior.

In this case the advancing ocean was perhaps making its progress by cutting a terrace quite as much as by subsidence. However, there is reason to believe that the area included within the west end of the Lake Superior Basin, *i. e.*, from the Animikie series to the Mesabi range, and thence to the Penokee series was submerged practically at the same time. For here we have three great formations of like character in identical order. The lowest formation, the quartzite and quartz-slate with conglomerates derived from the Basement Complex and the Lower Huronian, are the first deposit of the advancing sea. After this came a deepening of the water, when the calcareous and ferruginous formation, now constituting the iron-bearing member, was laid down. Then perhaps as a consequence of the upbuilding of this formation, came a shallowing of the water and the deposition of the great thickness of clayey sediments of the Upper Huronian. Since the last formation must have been deposited in shallow water, and yet is of great thickness, the bed of the ocean was probably subsiding during the remainder of Upper Huronian time.

At the end of the deposition of the Upper Huronian rocks, the Lake Superior region rose above the sea, and the atmospheric forces once more set to work. The orographic movement following the Upper Huronian, like that following the Lower Huronian, was locally intense, but in general the folding was of a gentle character. Along narrow axes the plications were so severe as to give the Upper Huronian rocks a foliated structure and com-

pletely crystalline schistose or gneissic character, but for the most part the changes in the Upper Huronian rocks are those of cementation and metasomatism. As with the Lower Huronian areas of intense plication, they are sometimes but short distances from those in which the rocks have been merely tilted.

How deep the Upper Huronian denudation went it is impossible to say. We only know that at a maximum, the Upper Huronian rocks are now 13,000 feet thick, and in certain other places are entirely absent, the higher members disappearing first and the lower members last. Thus the difference of the Upper Huronian denudation is measured by 13,000 feet. To this must be added the unknown thickness of the Upper Huronian rocks which have been wholly swept away, and the thickness of the Lower Huronian and Basement Complex, which were cut at this time. The thickness represented by these three elements i unknown, but it is probably great.

Of the outer limits of the Upper Huronian transgression, w are as ignorant as of the preceding ones, but certain it is that had an extent to the outer areas mentioned as belonging to th series. Beyond these limits no knowledge is available. Th original extent to the east, south and west of the Upper Huronia will probably never be determined, since the ancient rocks a covered by the Cambrian and post-Cambrian sediments. Wheth the transgression extended over the Great Northern area Canada to the Paleozoic deposits will doubtless be ascertain when this vast region is studied in detail.

The Keweenawan.—Again a change of conditions occurre and a great flood of basic volcanics, in beds of enormous thic ness were poured out. Later these were followed by more thin bedded volcanics. At about the same time a portion, at least, the Lake Superior region became immersed in the sea, since places the basement lavas of the Keweenawan are interstratifi with sandstone and conglomerates.

The Keweenaw series is composed lithologically of gabbr diabases, porphyrites, amygdaloids, felsites, quartz-porphyri etc., and of sandstones and conglomerates. The basic and a

rocks constituting the series are mainly surface flows. The gabbro flows are often of immense thickness. The diabase flows are usually much thinner, and frequently pass in their upper parts into porphyrites and amygdaloids. Many flows are porphyritic or amygdaloidal throughout. The beds of quartz-porphyry and felsite are abundant in certain districts, but usually have no great lateral extent, but while a single flow may be traced but a little way, frequently a group of flows of the same general character may have a great extent and thickness. But even the groups of flows cannot be regarded as general formations for the whole of the Lake Superior basin.

Since the number and thickness of the volcanic beds as well as the detritals vary greatly, the Keweenaw series as a whole is widely variable in different districts in its character and thickness. Structurally, Irving has divided the series into two parts, a lower division, in which eruptives are present, and an upper division, in which eruptives are absent. In any one section of the Keweenawan, at the lower part of the lower division, are generally found numerous volcanic flows, with few or no detrital beds. In passing toward the middle of the series the sandstones and conglomerates become more and more numerous and of greater thickness. Still higher the sandstones and conglomerates become predominant, and finally volcanic products disappear, the upper ten or fifteen thousand feet of the Keweenaw series being wholly composed of mechanical detritus. A given detrital bed varies from a mere seam of narrow local extent to thick beds of sandstone and conglomerate, one of which has been traced by Marvine for more than one hundred miles. The most general detrital formation is the upper sandstone and conglomerate.

The Keweenawan rocks extend about the entire area of the Lake Superior basin. They appear upon the east shore of Lake Superior, cover a large area of Keweenaw Point, northern Wisconsin, eastern and northeastern Minnesota, and a great area about Lake Nipigon. A similar set of volcanics, occupying a like stratigraphical position, is also known adjacent to Hudson Bay, and this may be a contemporaneous series.

The Keweenawan is the thickest of the series about Lake Superior, its maximum being estimated by Irving at the Montreal river to be fifty thousand feet. From this thickness it varies to nothing. This vast quantity of material does not, however, of necessity mark a period longer or perhaps even as long as the Lower Huronian or Upper Huronian, for the greater part of it is of igneous origin. The lava flows in their extent and thickness are to be compared with the great volcanic plateaux of the far West, rather than with local volcanoes such as Vesuvius, or the local volcanoes of the Upper Huronian and Lower Huronian. Associated with the lavas no volcanic fragmental material has been as yet discovered.

The source of the lavas of the Keweenawan is beyond th scope of this paper. It was, however, suggested that the fusio of a portion of the Basement Complex, and even Lower Huron ian, may have in part produced the deep-seated magmas, th extrusion of which produced the Keweenawan lavas.

In large measure the sandstones and conglomerates derive their materials from the volcanics of the series, but a lesser quan tity came from earlier series. This latter is particularly true the great detrital formation constituting the topmost member the Keweenawan. Partly because fragments derived from the fe sites and porphyries are more resistant than those from the bas rocks, acid pebbles are relatively abundant in the conglomerate

The fact that erosion was contemporaneous with eruption f much of Keweenawan time is to be noted. Certainly, when t period was well inaugurated, most of the Lake Superior bas was normally below the sea or near tide water. Many of t eruptions may have been sub-aqueous. Here and there volcar masses of such magnitude were built up as to rise above t water, and upon such areas, the sea at the base, and the air a rain above, immediately began their course of destruction. T acid and more viscous lavas may have formed the more pror nent elevations, and thus the attack was here more vigoro This may partly explain the predominance of the acid pebb in the conglomerates.

This great volcanic period was doubless one of unstable equilibrium, the lithosphere falling here and rising there. One of the final movements was the production of the Lake Superior synclinal. This synclinal movement affects not only the Keweenawan rocks, but the lower series, and in areas in which the unconformity between the Upper Huronian and the Keweenawan is not great, there is such a likeness in strike and dip of the two series as to suggest, at first, that the two are conformable. It is only as the contacts between them are followed for some distance, and the Keweenawan is seen to be now in contact with one member of the Upper Huronian, and now with another, that it is perceived that between the two there is an unconformity.

What proportion of the Keweenawan had accumulated before this Lake Superior synclinal began it is impossible to say. Possibly somewhere near the center of the Lake Superior basin were the larger foci, from which the great extrusions of lava occurred, and here a simultaneous sinking went on, such as is usual as a result of the upbuilding of a mountainous mass of volcanic material. This suggestion, if true, would also partly explain the apparent absence of volcanic fragmental material which naturally would accumulate near these foci.

Nowhere are the Keweenawan rocks so closely folded as to give them a schistose structure or a metamorphic character. Their induration is almost wholly a process of cementation.

The Cambrian Transgression.—At the close of Keweenawan deposition the Lake Superior region was again raised above the sea, and the pre-Cambrian erosion continued until the enormous thickness of Keweenawan deposits was wholly truncated. What must have been mighty mountains were reduced to mere stumps, or to base level. Following this denudation, the sea once more transgressed upon the land, and the horizontal Lake Superior sandstone was deposited. It now occupies many of the bays about Lake Superior. It once was much thicker, and perhaps covered all but the highest points of land. Certainly it or an overlying formation once was at least one thousand feet higher

than the level of Lake Superior, but it has since been almost completely removed, so that it occurs only in patches within the depressions of the older rocks.

Since Cambrian time no important orographic movements nor outbursts of volcanic material have occurred in the Lake Superior region, consequently the rocks have received little subsequent alteration. To these facts is due the possibility of outlining the pre-Cambrian history of this area with greater fullness than has been done in areas in which later disturbances have obscured the early history.

C. R. VAN HISE.

THE GLACIAL SUCCESSION IN OHIO.

In Ohio, as in other portions of the Mississippi basin, clear and unmistakable evidence of discontinuity in the drift deposition has long been recognized. Whittlesey, Newberry and Orton were among the first to announce the occurrence of buried soils in the North American drift, and they each drew illustrations from Southwestern Ohio. A few years later Professor Chamberlin discovered evidences of late advances in which the outline of the ice-sheet was very different from that of the glacial boundary. He also observed that the aspect of the drift is much fresher than in the outlying earlier drift. He further noted the evidence of valley erosion of considerable amount effected in the interval between the formation of two moraines, or more accurately two sets of moraines, in Western Ohio, the oldest of which is much younger than the earliest drift sheet, as will be seen below. My own studies, carried on under the direction of Professor Chamberlin, have brought out more fully the nature and value of these and other intervals which exist in that region. No less than nine of the twelve criteria for discrimination between glacial epochs set forth by Professor Salisbury in the opening number of this JOURNAL have been found, viz.: (1) Buried soils. (2) Buried fossiliferous silts. (3) Differential weathering. (4) Differential subaërial erosion. (5) Excavation of valleys between successive depositions of drift. (6) Changes in the course of ice-currents and in the outline of the ice margin. (7) Superposition of drift of different physical constitution. (8) Varying altitudes of the land. (9) Variations in vigor of ice action. Although the present state of knowledge of the Ohio drift is far from being as complete as one could desire, it seems profitable to review such evidence as throws light upon the value of the several intervals which mark the glacial succession in that state. In the western portion of


MAP OF THE
MAUMEE-MIAMI GLACIER
BY FRANK LEVERETT
Scale of Miles
OHIO
ERIE
Toledo
Cincinnati
KY.
GLACIAL BOUNDARY

EXPLANATION OF MAP.— This map was designed for another purpose, and hence includes only a portion of the district under discussion, though it represents the principal features herein discussed. Certain features, not discussed at this time, beach lines, eskers, esker troughs, etc., appear on the map.

The shaded portions of the map represent moraines, the shading being graduated to the strength of the moraine. Arrows indicate the position and bearing of striæ. Continuous lines are used to indicate the beaches of the Maumee basin and the south-western outlet of the lake which formed them. The second beach has not been fully traced, and is therefore incompletely represented. For the same reason the fourth and later beaches are not represented. Esker troughs are bounded by broken lines. The eskers which lie in them are indicated by continuous straight lines. The boundaries between upland and lowland tracts in southern Ohio are indicated by dotted lines. The glacial boundary, indicated by a broken line, appears for a short distance in the vicinity of Cincinnati.

the state there is a more complete and more easily deciphered record of the glacial succession than in the eastern portion, since the later advances there left a portion of the earlier drift uncovered. Our remarks will, therefore, relate chiefly to that district.

The full series of moraines formed by the Great Miami ice lobe, together with portions of the outer moraines of the adjoining East White River lobe on the west, and of the Scioto lobe on the east, are shown on the accompanying map. Outside the outer moraine of these lobes there is a glaciated district extending southward beyond the limits of the map in the main, its southern margin being the glacial boundary which lies fifteen to forty miles south from this moraine. That a long interval elapsed between the deposition of this outlying drift sheet and the formation of the outermost frontal moraine is shown below. Attention is called to it at this point, since it furnishes a convenient landmark in our discussion. The drift to the north of this moraine will be called, for convenience, by the general term, the later drift, while that to the south will be called the earlier drift. Both drifts have a somewhat complex history, and will be subdivided further on.

The earlier drift. For a few miles back from the glacial boundary in Northern Kentucky and in the hilly districts of

Highland, Adams and Brown counties, Ohio, there is a discontinuous or patchy deposit of drift, consisting in places only of scattering bowlders. In other places it consists of a clayey or sandy deposit, in which a few erratics are imbedded. In still others, notably at Split Rock and along Middle creek, west of Burlington, Kentucky, it consists of cemented coarse gravel. Only occasionally in the border portion is there a deposit of thoroughly commingled drift or typical till such as characterizes the thicker drift sheet immediately north. The attenuation seems due more largely to original deposition than to subsequent erosion.

Over the greater part of this earlier drift district back from the attenuated border one finds a nearly continuous deposit of till ranging from a few feet up to one hundred feet or more in thickness. It displays little or no aggregation in morainic knolls or ridges. The greatest thickness is found in filled-up valleys or in depressions, though the uplands in places carry as much as fifty feet of drift. Where less than twenty feet in thickness this drift sheet consists in the main of a yellow till. Where the drift has greater thickness a blue till is commonly found beneath the yellow. The blue till abounds in joints or irregular fissures filled with yellow or oxidized clay, a feature which is rare in the later drift sheet, and may, perhaps, constitute an important line of evidence as to the age. Both the yellow and the blue till are harder than those of the newer drift. The indurated character of this earliest drift sheet is apparently due to a partial cementation with lime, the drift being highly charged with a calcareous rock flour, a glacial grist.

The earlier drift seems to have been deposited in this district without great abrasion of the rock surface. No striæ have been found, though repeated search was made for them. (In districts further west striæ are occasionally found beneath the earlier drift). Between the blue till and the underlying rock there are frequent exposures of a few feet of earthy material having the appearance of residuary clay, or, if this be absent, a very rotten rock surface is usually found. In one village (Mt. Oreb) well

sections are reported to have passed through a black mucky clay, probably a preglacial soil, immediately beneath the blue till and a few feet above the rock surface. This feeble abrasion is thought to be due to lack of vigor in the ice-movement. The attenuated border is apparently due to the same lack of vigor and to a comparatively short occupancy of the region by the ice-sheet. The lack of vigor in this earlier invasion is in striking contrast with the vigor of the invasion which produced the outer moraine of the Miami and Scioto lobes, there being numerous exposures of striation in the district immediately north of that moraine, while the moraine itself bears evidence that the ice-sheet had great shoving power.

There is a possibility that this earlier drift sheet embraces two distinct periods of deposition. Evidence in support of this view is cited by Professor Orton in his report on Clermont county, Ohio (the county bordering the Ohio river just above Cincinnati), viz., that a buried soil and deposit of bog iron occur at the junction between the yellow and blue tills. From Professor Orton's account it would appear that no marked oxidation of the surface of the underlying blue till had occurred before the yellow till was deposited. We infer from this that the interval of deglaciation may have been comparatively brief, though it is possible that swampy conditions, such as prevail in the production of bog iron, prevented oxidation during a prolonged period. Inasmuch as Professor Orton is a careful observer and cautious writer, I do not feel free to question the evidence he cites, but my examinations in this district have not confirmed his evidence, so far as the location of the soil bed at this particular horizon is concerned. I have found testimony as to the occurrence of buried wood at or near this horizon, but not of soil beds. Possibly Professor Orton considers the occurrence of wood good evidence of an old land surface, but in view of the fact that wood may be incorporated in the drift as a part of the glacial debris I have not thought this a sure evidence. In the lists given in the Ohio reports, Dr. Newberry cites instances of wood to prove the existence of a "forest bed," and forest

bed and soil are terms which are used interchangeably in the Ohic Geological Reports. It ought also to be stated in this connection that a few miles to the north a buried soil occurs beneath the till, but it lies within the district covered by a later invasion of the ice, and the horizon is, I am convinced, above that of the one in question. There is also a soil above the yellow till of this earlier drift sheet which is buried by a silt deposit, as described below. I feel, therefore, that it is necessary to refer to different horizons the instances that have been reported from south-western Ohio.

Deglaciation interval with development of a soil attended by oxidation, leaching and erosion of the earlier drift sheet. Except where erosion has removed it a capping of silt several feet in thickness is found upon the surface of this till sheet. It is clearly of much later age than the till, being separated from it by a sufficient interval for the development of a soil, and fc a large amount of oxidization and leaching and erosion. Th silt is discussed below.

The soil which was developed on this till sheet does nc commonly show a black color, though exposures of such a sc color are met with in all parts of the district outside the out moraine. The evidence of a land surface is more general found in the deep brown color, and weathering or soil-producir disintegration of the upper part of the till. The deep brov changes gradually below to the ordinary yellow color of oxidiz till, but at top it terminates abruptly at the base of the ove lying silt. The color of the silt being much lighter than that this brown soil the contrast is very marked. The deep brov color extends usually to a depth of two feet or more, while d coloration extends to six or eight feet. The amount of discolo tion is somewhat greater than is commonly found at the prese surface of the newer drift. Repeated comparisons of the soil the two districts lead to the conviction that this older drift sh had been exposed as a land surface for a longer time before t silt was laid upon it than has the outer moraine of the nev drift up to the present date. The same conclusion is reach

upon comparing the amount of leaching in the two districts. In the earlier drift sheet it is rare to get a response with acid within six to eight feet of the surface, whereas in the newer drift the leaching has seldom been carried to so great a depth as six feet. It seems clear from the position and relations of this old surface that the leaching took place before its burial.

Concerning the amount of valley erosion accomplished in south-western Ohio during this interval no conclusion was reached. Sufficient time was not given to the study of the region to successfully eliminate the effects of post-glacial erosion and of erosion accomplished between the deposition of the silt and the invasion which produced the older moraine of the later drift. In eastern Indiana, however, there are exceptionally favorable conditions for determining the amount of erosion accomplished between the deposition of the earlier and later drift sheets, and it is believed that data of some importance can be furnished. Near the head waters of the Whitewater river there is a district covered by a thick deposit of drift. We may judge from wells made on interfluvial tracts that the level of the rock surface in that region is no higher than the valley bottoms of the several headwater tributaries of West Whitewater, and these valleys are, therefore, simply channels cut in the drift. The evidence all opposes the view that the ridges and valleys are in any way dependent upon preglacial erosion. The valleys along these headwater tributaries of the West Whitewater (Noland's fork, Green's fork, and West fork) are conspicuous for their size, their width being one-fourth to one-half mile or more and their depth sixty to one hundred feet. A similar broad valley is occupied by the headwaters of East Whitewater, though this stream has, since the later ice-invasion, cut a narrow gorge down into the rock strata.

This district of eroded drift was overridden by the western edge of the Miami and the eastern edge of the East White River lobe of the later incursion, but it so happens that the amount of drift deposited does not greatly conceal the outlines of these old valleys, the general thickness of the later drift sheet in this region

being not more than thirty to forty feet. The outer moraine of the East White River lobe, after following an upland tract west of the West Whitewater northward for some distance, descends, near Cambridge City, into the valley of the West fork of West Whitewater, and after crossing this valley rises near Hagerstown onto elevated upland. The outer moraine of the Miami lobe also, in crossing Noland's fork, south-east of Cambridge City, descends into and is developed in the valley as well as on the bordering ridges. That the valleys were formed previous to the deposition of this moraine, there can be no doubt, and being made entirely in the drift, as noted above, they show clearly that their excavation must be confined to the interval between the deposition of the earliest drift sheet and that of this moraine. The amount of erosion is several times as great as that accomplished by the streams that have traversed this valley since the moraine was laid down. The size of the streams which formed them constitutes an important factor in determining the time required in this excavation. That these interglacial streams were not much larger than those now traversing this region seems probable from the fact that within a few miles north from the sources of the present streams, the general slope of the country becomes northward, so that drainage would naturally be in that direction, instead of southward along the Whitewater The erosion here displayed seems, therefore, to indicate the lapse of a longer interval between the deposition of the earliest drif sheet and that of the outer moraine of the later drift, than th time that has elapsed since the formation of that moraine How much of this interval preceded the silt deposition, it i difficult to determine, because the outer moraine has conceale the silt. Light upon this question should be obtained upon care ful study of the lower portion of the Whitewater valley and c other valleys lying within the silt-covered district and outsid the moraine, but this line of study has not yet been unde taken.

Depression accompanied by silt deposition. The silt which found on the upland outside this moraine, has been discussed a

some length, in a recent paper.[1] It need, therefore, be but briefly touched upon here. It is there shown that it forms a practically continuous sheet over the southern portion of the glaciated district in Ohio and Indiana, and extends to an undetermined distance over the unglaciated districts of Ohio. It also appears on the uplands in Kentucky, south-west of Cincinnati, and may appear further east in that state. It has been found along the margin of the glaciated district in Ohio as far north-east as the vicinity of Newark, but has not been observed farther north and east.

The thickness of this silt decreases in passing southward, especially on the interfluvial tracts of south-western Ohio and south-eastern Indiana, a fact which seems to indicate that its source was from the north rather than from flooded conditions of the Ohio river. From evidence gathered in the upper Mississippi region, it is thought to be the correlative of a sheet of glacial drift not exposed to view in these states, or at least not yet discovered. Its thickness in the northern part of the district, next to the outer moraine of the newer drift, is four to six feet or more while on the borders of the Ohio river it scarcely exceeds three feet, and in places is two feet or less. Wherever examined it is found to be thoroughly leached. This fact is thought to be of importance in showing great age, especially on the theory of the glacial origin of the silt, since glacial silts, as well as till, in regions underlain as this region is by limestone, contain a large amount of calcareous material.

The amount of depression involved in this subsidence is difficult to determine. As yet such data as have been discovered bearing upon the altitude of the land, either previous to or during the depression, are not precise, though it seems probable that the altitude was several hundred feet lower at the maximum of depression than at the present time, while before the depression the drainage appears to have been good, and we may suppose that the altitude was not much lower than at the present time.

[1] "On the Significance of the White Clays of the Ohio Region." American Geologist, July, 1892.

Re-elevation of the land. Between the deposition of this silt and the formation of the outer moraine of the later drift, the altitude appears to have become about as great as at the present, since, as shown below, the gravels deposited at that time along valleys leading away from the ice margin bear witness of vigorous drainage.

Outer moraine of the later drift. Since the position of this moraine is indicated on the accompanying map, it need not be outlined. It should, however, be stated that this moraine is overridden by a later one a few miles east of Hillsboro, Ohio, and has not been recognized in the eastern part of the State. The moraine consists of a ridge of drift one to two miles or more in width, standing, as a rule, but twenty to forty feet above the outer border plain. Its surface is gently undulating, there being but a few sharp knolls or ridges, such as characterize the surface of a later series of moraines described below. It is composed mainly of till, though gravel deposits are not infrequent, either in the low knolls or in beds or pockets incorporated in the body of the drift.

Striæ are numerous in the district immediately north of this moraine, and since the usual bearing is toward the moraine and not toward the glacial boundary, it seems evident that they were produced at the time of the later invasion. Some striæ near Cambridge City, Indiana, appear to be out of harmony with the ice-movement of the later invasion, and may, therefore, be older.

The older drift was but partially removed by this later invasion, and it is frequently encountered in wells and exposed in bluffs of streams. It is harder and dryer than the newer drift. In a few places, notably at Marshall and Martinsville, in Highland county, and in the vicinity of Wilmington, in Clinton county, a black soil is found at the base of the newer drift. I have seen it only at Wilmington, but Prof. Orton, in his report on Highland county, calls attention to its occurrence at Marshall and I was told by well diggers of its occurrence in Martinsville. In Wilmington it is exposed in a railway cutting near the public school building, in the west part of the village. It consis

of black muck, several inches in thickness, overlain by till, and underlain by a yellowish sandy clay. The exposure only extends a foot or so beneath the muck, hence but little is known as to the character at this point of the underlying drift sheet. Dr. Welch, of Wilmington, has found pieces of coniferous wood imbedded in the soil in this and other exposures in that vicinity. He has preserved one piece which shows beaver cuttings. He has also discovered seeds of various plants imbedded in the muck, some of which now flourish only in higher latitudes. The contents of this muck-bed seem, therefore, to indicate an interglacial climate less genial than the present.

In his report on Montgomery county, Ohio, Professor Orton described a buried peat-bed exposed in the bluff of Twin creek, near Germantown. This peat contains the berries and fine twigs of cedar. At the time of Professor Orton's visit, in 1869, the peat was exposed for a distance of forty rods, and had a thickness of twelve to twenty feet. It was underlain by a bed of gravel. At the time of my visit, in 1889, its exposed thickness above the creek bed was about eight feet. It would seem, therefore, that the peat deposit has a somewhat lower altitude where now exposed than where Professor Orton saw it. Professor G. F. Wright, who has also seen the peat-bed, has suggested (Bull. U. S. Geol. Survey, No. 58, pp. 96-97) that it occupies a large kettle-hole, and that the higher portions of the peat-bed were near the rim. This peat-bed is overlain to a depth of 90 to 100 feet by a fresh-looking drift, mainly till, and evidently of the newer drift series. This locality is north of a later moraine than the one under discussion. It is not known whether the peat was accumulated during an interval of deglaciation between the formation of that moraine and the later one, or at an earlier time. The later interval seems to have been sufficiently protracted for the accumulation of this amount of peat.

Several wells in the east part of Wilmington have passed through a fossiliferous silt between the newer till and an older drift-sheet at a depth of about thirty feet. A few minute gasteropod shells obtained from this silt by Dr. Welch await specific

determination. None of them exceed one-sixth of an inch in diameter. Professor Chamberlin reports having observed a bed containing molluscan shells between the newer and older till-sheets at Greensburg, Indiana. (See Third Annual Report U. S. Geol. Survey, p. 333). Positive evidence is wanting as to whether these fossiliferous silts are of the same age as the silts which cover the district outside the moraine, but they appear to have about the same horizon. No fossils have been found in the silts outside the moraine. It seems not improbable, however, that if originally present their exposed situation is such that the fossils may have been dissolved and removed by leaching.

In the case of streams leading southward from this region of newer drift, careful discrimination is necessary to decide the age of terraces. The coarse, gravelly terraces of the Little Miami valley are referred to the stage when the outer moraine was formed. This valley carried a larger volume of water at that time than in later stages of glaciation, because it was more favorably situated for receiving glacial waters. The Great Miami valley was apparently flooded as much during later stages as at this time, and its gravels are largely of the age of the later moraines. The Little Miami gravels are made up, in large part, of coarse material as far down as the mouth of the stream, pebbles two to four inches in diameter being common. The coarseness of the material testifies to a fair gradient, presumably as great as the present altitude of the country affords. The gravels rise to a height of but fifty to one hundred feet above the present stream, and are near the bottom of the valley trench, for the uplands bordering this stream stand 300 feet or more above its bed. The flood stages, though characterized by a much more vigorous drainage than that which obtained while the silt was being deposited on the bordering uplands, did not reach by nearly 200 feet the limit reached by the silt-depositing waters—a fact which seems to be capable of explanation only on the assumption of great orographic movements.

Deglaciation interval in the later drift series. In his reconnaissance of Western Ohio, some ten years ago, Professor Chamber

lin observed decisive evidences of the lapse of a considerable interval between the formation of a moraine lying east of Mad river, near Urbana and Springfield, and the moraines on either side of it, the moraine on the east being one of the later Scioto moraines, while that on the west is a Miami moraine. This older moraine proves to be the outer moraine of the Miami lobe (see map). While this moraine was being formed the Miami lobe occupied the Mad river drainage area, and the waters from the melting ice-lobe were forced toward the south into the Little Miami valley, passing just east of Springfield. The course is well defined, there being a gravel plain leading south along the east side of this moraine. The altitude of this gravel plain is much greater than that of the immediate bluffs of Mad river valley, but is lower than the water-shed between the Mad river and the Scioto river system, just east of it. It consequently presents somewhat the appearance of a broad irrigating ditch, following the face of a slope at a considerable altitude above the stream. When the ice had retreated from the Mad river basin the drainage of the high country to the east of Mad river soon opened channels directly across this gravel plain and the moraine west of it down to the trough in which the river flows. Similar channels were formed by streams leading down to Mad river from the elevated country west of its basin, and a broad valley was opened along the axis of the trough. When a fresh advance of ice occurred the Miami lobe came nearly down to the Mad river valley from the west and covered the upper portion of the western tributaries. Its moraine, in crossing the interglacial valleys, descends into them, but only partially fills some of them, thus repeating the phenomena of the outer moraine, in the Whitewater valley, as noted above. Similarly, the Scioto lobe trespassed on some of the eastern tributaries of Mad river, and its moraine partially fills the interglacial valleys. It should, perhaps, be stated that these interglacial valleys do not follow preglacial troughs, but instead, have bluffs standing as high as the interfluvial portions of the slopes of the basin. Their excavation began with the retreat of the ice-sheet from the outer Miami

moraine lying east of Mad river. It is difficult to determine the precise amount of excavation accomplished in this interval, since the portions of the valley lying beneath or within the later moraine are partially filled, while the portions lying outside the moraines afforded avenues for the escape of glacial waters, and were probably much enlarged thereby. It seems safe, however, to state that an amount of excavation took place that would require some thousands of years with a drainage system of the size of the present Mad river system, and with a gradient such as the region now affords. It may be added that in regions further west, if our correlations are correct, there are found evidences of the same deglaciation interval, but their discussion does not fall within the scope of this paper.

Main morainic system of later drift. The moraine just referred to (in whose re-entrant angle the Mad river basin lies) belongs to the system mapped and described by Professor Chamberlin, in the Third Annual Report of the U. S. Geol. Survey, as the "Terminal Moraine of the Second Glacial Epoch." As shown by Professor Chamberlin this moraine lies near the glacial boundary in eastern Ohio and north-western Pennsylvania, but farther west it falls short many miles of reaching the glacial boundary. It is a complex system, "constituting a belt rather than a single moraine," there being in places not less than four distinct members. Nearly everywhere in the state it presents a sharply indented surface, a feature which, as suggested by Professor Chamberlin, appears to indicate forceful or vigorous action of the ice-sheet. Its peculiarly sharp contours and their diagnostic characters make it the most conspicuous and distinctive morainic belt in the state. Other moraines, newer as well as older than this morainic system, assume in places the form of smooth ridges or have but gently undulating surface, and hence are less conspicuous features even where they have as great bulk as the individual members of this system. In western Ohio one of the members of this system (the second one of the group) carries on its surface large numbers of crystalline bowlders of Canadian derivation and the remaining members are liberally

supplied. In this respect this morainic system contrasts with all other moraines of Ohio, and especially with the later moraines, there being but few bowlders on their surfaces. In eastern Ohio bowlders are a less conspicuous though not a rare feature. The cause of this unusual abundance of bowlders is an interesting problem and one perhaps not easily solved. It has been suggested by some one, I think it was Mr. McGee, that an unusual abundance of bowlders on the later drift sheets may be an indication that the ice invasion which brought them in was preceded by a long deglaciation interval in the gathering ground, and that the Canadian highlands were scoured afresh after the lapse of sufficient time for ledges to have been seamed and broken under atmospheric influence. The suggestion seems worthy of careful consideration.

The drainage from the ice-sheet was especially vigorous at this time throughout the entire width of the state and as far to the east and west as this morainic system has been identified. The altitude could not well have been less than at present, and may have been somewhat greater.

The later moraines. Between this morainic system and the western end of Lake Erie six more or less distinct moraines occur, which were probably formed in comparatively rapid succession. They each consist usually of a broad ridge one or two miles or more in width, and twenty-five to fifty feet in height. They are each sufficiently bulky to have determined to a large extent the courses of the main drainage lines of northern Ohio (see map) and yet they seldom present a sharply indented or conspicuously broken surface. The overwash aprons and terraces connected with them indicate less rapid discharge of waters than from the earlier moraines, and that too in certain parts of the belts where conditions were very favorable for rapid escape of waters as in the north part of the Scioto basin. It is thought from this feature as well as from the aspect of the morainic ridges themselves, that the ice-sheet had less vigor than when forming earlier moraines. That there was a decrease in altitude seems also highly probable. As noted above, surface bowlders

are of comparatively rare occurrence, being apparently no more plentiful than in the body of the drift. The aspect of this group of moraines is so very different from that of the group which lies outside it, that it is thought not improbable that they are the product of a distinct invasion. No decisive evidence of a long deglaciation interval separating the two groups has, however, been discovered.

Summary. From the facts above presented the following stages of the glacial period seem sustained:

1. A glacial stage during which the ice-sheet extended farther south in western Ohio than in any later stage. This stage will need subdivision in case a buried soil horizon in the midst of its deposits be well substantiated.

2. A long stage of deglaciation marked by development of soil and by attendant oxidation, leaching and erosion of the drift sheet.

3. A stage of silt deposition during which the highest points in south-western Ohio apparently became covered at flood stages. From evidence gathered elsewhere it seems probabl(that the silt deposition accompanied a glacial stage whos(deposits are concealed in this region by later drift sheets.

4. A glacial stage, during which the outermost well-define(frontal moraine was formed. The drift of this stage is conceale(in eastern Ohio by the later moraines. Preceding this stage i an interval during which the valleys became opened again t(such depth that the main streams, at the time of this later ic invasion, flowed at levels 200 feet or more below the level of th upland silt.

5. A stage of deglaciation of considerable length as ind: cated by valley excavation.

6. A glacial stage characterized by sharply indented mo ainic ridges, thought to indicate vigorous action. The ice-she(reached about to the glacial boundary in eastern Ohio, but fe short many miles of reaching the boundary farther west.

7. A glacial stage characterized by morainic ridges (smooth contour. This stage embraces the final disappearance (

the ice-sheet from Ohio. A deglaciation interval is believed to have preceded this stage, but as yet, decisive evidence in support of this view is not obtained.

We may now profitably review what is known concerning the altitude in each stage:

1. During the earliest advance little of value is known in this region. The scarcity, if not absence, of coarse overwash material seems to indicate feeble drainage and consequent low altitude. It is true that the Split rock and Middle creek conglomerate indicate powerful water action, but if formed as they appear to have been beneath the ice-sheet, they show little as to the altitude of the land.

2. During the period of deglaciation following the deposition of the earliest drift there appear, from the character of the changes effected, to have been fair drainage conditions. We may presume, therefore, that the altitude was not much lower than the present altitude of the region (800–1000 feet A. T.).

3. During the period of silt deposition there can be little doubt that the region stood several hundred feet lower than now.

4. During the formation of the outer moraine of the later drift there were apparently as good drainage conditions as are now afforded in the western Ohio region.

5. During the succeeding deglaciation interval the erosion effected indicates a fair altitude.

6. During the formation of the main morainic system the maximum of elevation was probably reached, there being an especially vigorous drainage at that time, not only in Ohio, but as far to the west as the moraine has been correlated.

7. During the formation of the later moraines there seems to have been a return to low altitude, and still later the Champlain submergence of the coast and St. Lawrence occurred. It is important to note that the Champlain submergence is separated from the submergence which produced the silts of southern Ohio by the periods of high altitude just mentioned, a succession of

periods during which all the Ohio moraines, no less than twelve in number, were being formed.

The decision as to the relative length of the intervals of deglaciation is obviously dependent upon data gathered from the entire glacial field, and should not be rendered in the light of what can be gathered from this limited region.

FRANK LEVERETT.

TRACES OF GLACIAL MAN IN OHIO.

TRENTON and the Delaware Valley no longer have exclusive claims to reputed evidences of glacial man. For a number of years reports have come from the West of finds of implements in ice-age drift. Miss Babbitt in Minnesota, Cresson in Indiana and Metz and Mills in Ohio, have in turn announced the discovery of specimens of these rare and precious mementos of antiquity. I have already, in papers published in THE JOURNAL OF GEOLOGY and in the *American Geologist,* raised questions as to the proper interpretation of the finds in Trenton and at Little Falls, Minnesota. A brief study of the Ohio finds may now be undertaken with a view of presenting and weighing such doubts as may have arisen with respect to the value of the evidence furnished by them. I have endeavored in this, as in the other cases, to keep well within the bounds of legitimate criticism, desiring to allow all that can be justly claimed for the evidence presented in support of the theory of a glacial paleolithic man in America. In dealing with this subject, however, I have found it necessary to keep in mind the fact that the evidence to be considered has been collected and presented by advocates of the paleolithic theory who have welcomed finds without critical scrutiny, and have reached and presented conclusions as much because they were in the line of the expected and desired, as because they were actually susceptible of demonstration. The advocates of the theory have naturally taken every opportunity to emphasize the importance of the evidence collected as viewed from their own standpoint. To insure correct final judgment it is necessary that other points of view be taken and that the evidence be subjected to every possible test. I shall confine myself to fields in which I have made personal and most careful observations. I do not desire to secure the acceptance as final of any particular view with respect to the history of early man in America. I am not intro-

ducing or advocating a theory but attempting to insure the non-acceptance of any theory, howsoever plausible, that is not supported by conclusive proofs. Others have undertaken to show how much proof Ohio has furnished in support of a particular hypothesis; they cannot now object to my attempting to show how insignificant this proof really is.

At the meeting of the American Association for the Advancement of Science in Washington, in 1891, much attention was paid to glacial geology, and one paper by Mr. Frank Leverett, of the Geological Survey, treated of the gravels of Loveland, Ohio, and of the finds of implements in them by Dr. C. L. Metz. Mr. Leverett was then about to return to Ohio and I resolved to accompany him to the Little Miami Valley with a view of making a brief preliminary study of the gravels and their contents. A week later Dr. Metz joined us at Loveland, and we proceeded at once to the great gravel pits just west of the village. Gravel was then being taken by the Baltimore & Ohio Railway Company from the south side of the road, two hundred yards beyond the bridge, but the old pit is a little farther on and on the north side of the road, the excavation running into the high terrace from the track at an oblique angle. The excavation is upward of two hundred yards long, and is from two hundred to three hundred feet wide, and has an average depth of perhaps twenty-five feet. The west wall had not been worked recently, and was reduced by erosion to a steep slope covered with vegetation The curved wall of the east side was thirty or more feet higl and very steep, affording an excellent exposure of the gravels these consisted of very coarse material laid down in heavy irregular beds. At least one-fourth of the mass consiste of sub-angular or but imperfectly rounded slabs and flattis masses of limestone, which lay flat or with a slight inclinatio toward the river. The larger slabs, which were often as muc as two feet or more across, projected like steps or shelve from the wall. The remainder of the deposit consisted of smaller rounded masses and bits of limestone; of masse bowlders and pebbles of granitic rock constituting perhaps on

twentieth of the deposit, and of gravel, sand and calcareous powder.

There were, in places, indications of rude lenticular bedding of these materials with a pretty uniform general inclination toward the channel of the river. The appearance of newness exhibited by these deposits was wonderful; the surfaces of the stones were smooth and clean, and many of the interspaces were open as if formed but yesterday. A closer examination showed, however, that this appearance of newness was partly due to the fact that the waters charged with calcareous matter penetrated the superficial beds, partially setting the constituent parts and in a measure sealing the apertures, thus preventing the complete settling and filling that otherwise would have taken place. The constitution and conditions were pretty uniform throughout the section, save at the top where there was a deposit from two to four feet deep of ferruginous sandy loam, containing some fragments, pebbles and bowlders of several varieties of stone.

After three visits, and the most careful but entirely fruitless search for relics of art from bottom to top of the gravel walls, I found myself wondering whether there had not been some mistake, whether the objects found were really tools, or whether the collector had not mistaken materials descended from the surface deposits for gravel in place. It is unfortunate that the statements of collectors in such cases, correct or incorrect, cannot readily be subjected to competent tests of verity; we must be content with hedging them about with all available restrictions in the way of negative evidence.

Having, during the first visit, examined the site at some length, we proceeded to the office of Dr. Metz, in Madisonville, and were shown two objects obtained from the pit at a depth of about twenty-five feet beneath the surface. The smaller of these, a dark flattish piece of cherty, slightly water-worn stone, was rudely flaked along one edge, but the evidence of design was not at all convincing, and it seems useless to place the specimen in evidence. The other object was apparently a work of art, exhibiting decided indications of design. It was found in

the main gravel pit about twenty-five feet from the surface, by Dr. Metz, who expresses his full belief that it was in place in the gravels when found. A third slightly flaked stone from the same locality and position had been forwarded to the Peabody Museum at Cambridge. On examining this specimen at a subsequent date I found that it has no features that can with certainty be described as artificial.

It is not from a desire to discredit the observations of Dr. Metz, who is a most reputable and more than usually capable observer, that I raise the question of the verity of these finds. It is essential, in a case where so much depends on the finding of a single specimen, that every observation relating to it should be placed upon record in such a way that, in the future, judgments as to the value of the evidence may not be based entirely upon the testimony of a single observer whose acquirements may be restricted or whose preconceived notions may give a very marked bias to his observations and deductions.

Referring to the Loveland site, it may be remarked in the first place that it seems improbable that man would have occupied an area overrun by torrents capable of transporting, and transporting almost exclusively, the coarse materials forming these deposits, and the chances of the preservation of artificial features of specimens brought by floods from the valley above are extremely slight.[1] Of course, if man existed here during the glacial period, he may have sought the raw material for his rude arts on the banks of this stream during the periods of of low water and may have thus left the refuse of his shaping operations at almost any point; but a single specimen cannot considering possible errors of observation, be regarded as sufficient for the establishment of such a conclusion.

In the second place, I may mention the fact that on carefully examining the Loveland specimen, I found it partly covered with dark, well-compacted earth, resembling the soil of the surface o

[1] The edge of the continental ice sheet was, according to Mr. Leverett, only abo eight miles distant when these gravels were formed, which makes the probability finding implements here still slighter.

the terrace, rather than the light-colored, fine-grained calcareous powder characterizing the matrix, such as there is, of the gravel deposits. It seems to me that there is in this observation, made also by Mr. Leverett, and still subject to verification if the specimen has not yet been cleaned, sufficient ground for raising the question as to whether it is possible that Dr. Metz could have mistaken a surface mass, descended into the pit from above, for gravel in place. Dr. Metz, or any other observer not a professional student of geologic phenomena, especially of talus phenomena, involving materials subject to resetting after degradation, or to sliding *en masse*, could readily be excused for making a mistake of this kind. Lest this suspicion of error should seem unfounded or uncalled for, I have prepared two sections, Figs. 1 and 2, which illustrate some of the many dangers besetting the way of gravel searchers. In Fig. 1, an ordinary profile, resulting from the removal of gravels for railroad ballast, is shown. Deserted by the workmen for a day or a week, objects from the surface deposits, *A*, may have fallen into the pit resting at *B*. The sliding of the mass, *a b*, might cover them to the depth of several feet, *C*, Fig. 2, and the effects of disturbance upon the surface are soon obscured or obliterated by weathering. Suppose now that Dr. Metz, or any one else, should appear upon the scene as the fallen mass is removed and penetrated by workmen, and should witness the uncovering of art forms at *D*, twenty-five feet beneath the surface of the terrace. It is vain to hold that there is no danger of mistake in such a case; the chances of error are really very great, and a little slip like this in observation would falsify the chronology of human history in this valley to the extent of some thousands of years.

It may be remarked that the terraces of the Little Miami were for a long period occupied by mound-building tribes whose implements and refuse of manufacture are scattered everywhere, and it is entirely within the range of possibility that such a partially worked specimen as this should have been left by them in the surface loams on the site of this pit at Loveland.

As to the nature of the object itself, a number of questions

may be raised, and we are justified in making all possible inquiries. It is a pick-like object, some six inches long, and perhaps two inches thick toward the larger end. The head is rounded, as if intended to fit the hand, and there is even an appearance, deceptive, no doubt, as will appear further on, of abrasion by use. The sides are neatly flaked, the apparent result of blows by a hammer, many of which seem to have served only to batter the edges, while others appear to have removed a series of flakes extending along the shaft from the head to near the point. The smaller end of the object is worthy of especial notice; the point, which probably was originally sharply pyramidal, has been removed by an oblique fracture, leaving a clean, unworn surface. A portion of the surface adjacent to the truncated point has not been shaped by flaking, but retains the original minutely granular weathered surface, indicating that the stone before flaking or remodeling was already pointed. The object was therefore not used after the breaking of the point, as the unworn fracture shows, and the presence of the unaltered original surface adjacent to the present point would seem to prove that it never was subjected to use. The material appears to be a fine-grained, light-colored limestone, having a conchoidal fracture. It is soft and brittle, and is not likely to have been employed in making tools, and especially pick-like tools. This observation leads to an inquiry as to whether it is possible that the flaking could have been the result of natural agencies, such, for instance, as the crushing and abrading forces exerted by moving ice. Could a pointed bit or mass of brittle limestone have been so squeezed between moving impinging rocks as to remove these flakes and to produce the battered and rounded effect seen upon the edges and head, respectively, of this object without affecting the point, save to break it, and without breaking the shaft elsewhere? That natural forces do occasionally produce forms resembling those of art is well known, and that archæologists have at times been rash in accepting such as artificial cannot be denied.

To more fully inform myself upon this topic I made careful examinations of the contents of the moraine from which por-

tions, at least, of these gravels descended. I was somewhat surprised with the results, which proved so interesting and suggestive that they may well be referred to in this place. In a railroad cut recently made through morainal deposits near South Lebanon, about eight miles north of Loveland, I found numerous pieces of this brittle limestone, varying from minute bits to masses a foot or more in greatest dimension, showing traces of fracture and flaking resembling somewhat closely those of the implement or object found by Dr. Metz at Loveland. Indeed, some of these specimens are so well flaked that I would, under ordinary circumstances, not hesitate to call them artificial. In fact, all may be artificial, although the shapes are often eccentric, and the size, in cases, is greater than in any known flaked tool. It is a significant fact that nearly all the stones found in the deposit are covered with glacial striæ, and some of the conchoidal faces of the implement-like objects are scratched, through movements of the ice. It is true that man may have lived or hunted on or near the ice, and his tools or the refuse from their manufacture may have been taken up by the ice, passing afterwards into the moraine; but that they should enter the ice in numbers, and so become striated through its movements, is highly improbable. The Loveland specimen has, however, a more decidedly artificial character than any of these, and were its inclusion in the gravels fully verified, and were it not alone and practically unsupported by other finds, it could well be accepted as important evidence of glacial occupation by a stone-flaking people.

Besides the Loveland finds, Dr. Metz obtained a specimen of rudely flaked black chert from a cistern which he was sinking in Madisonville, Ohio. It was found at the surface of, or slightly imbedded in, gravel beneath a bed of silt eight feet thick.[1] Dr. Metz is a careful observer, and it is hard to believe that he would have permitted himself to be deceived although all must

[1] Putnam, F. W. Proc. Boston Soc. Nat. Hist., Vol. XXIII, p. 242.

Wright, G. F. Ice Age, pp. 530-532.

Leverett, Frank. Am. Geologist, March 1893, p. 187. According to Mr. Leverett it is not certain that these silts belong to the ice age, and if not, the find is no evidence of glacial man, whatever else it may signify.

admit the possibility of such deception. I have examined the specimen, now in the Peabody Museum, and find it to be identical in every essential feature with typical rejects of the modern blade-maker, lacking the least indication of specialization. It is not safe to call it an implement, no matter what its age, and to present it as evidence of paleolithic culture is little short of folly.

The discovery of a number of ancient hearths on the banks of Little Miami river was announced several years ago, and may be referred to in this place, since they were associated with deposits of ancient-appearing gravel. Professor Putnam gives the following information in regard to them: An exploring party "discovered five ancient hearths half a mile down the river from the Turner group of earthworks. These hearths were exposed by the river cutting away its bank. The lowest of the five . . . is thirteen feet below the surface of the bottom land, and rests upon a layer of gravel seven inches thick, upon which rest ten feet of alluvial deposit. This is by far the lowest and most ancient of the many hearths which from time to time have been exposed by the action of the river, as first noticed several years ago by Dr. C. L. Metz, who has examined a number of these ancient fire-places, and on one found fragments of pottery, which he sent to the Museum last year. These hearths are made of small boulders, in each case covering an area of several square feet. These stones are burnt, and many are splintered by heat. Upon the stones forming this oldest hearth was a considerable quantity of ashes and charcoal, but no other evidence o: the work of man. These hearths furnish evidence of the occupation of the bottom land at different intervals during the form ation of this deep deposit, filling the valley for miles in extent That in this lowest hearth we have a considerable antiquity i self-evident; but how long after the formation of the glacia moraine, from which the gravel overlying it was derived, wil only be determined by a careful study of the geology of th whole valley.[1]

[1] Putnam, F. W., 23d and 24th Annual Reports of Peabody Museum, p. 92.

In 1891 I visited this site with Mr. Frank Leverett. Traces of the fire-marked stones were found, but the waters had removed the hearths previously observed. A critical examination of the sedimentary deposits leaves the impression that they are quite modern. The upper surface is but little above the present flood plain, and has the appearance of a modern alluvial deposit of black, loamy earth, including thin irregular layers of fine gravels. I see no reason, considering the facility of mutation characterizing such deposits, why the hearths may not have belonged to the occupants of the site of the noted Turner group of mounds near by. It is seen from Professor Putnam's report that there were many hearths in and beneath these works. "An examination was also made of the surrounding embankment of the work, and much to our surprise portions of it were found to cover large areas of burnt stones. Several of these old fireplaces were explored inch by inch with the trowel, and in the ashes and among the charcoal were found numerous pieces of the bones of various animals, many potsherds, flint chips, broken and perfect implements, ornaments of several kinds, pieces of mica, etc., all similar to what has been found in previous years at other places in this interesting group of earthworks."[1] It may, I believe, be taken for granted that these hearths, notwithstanding their intimate relations with deposits of gravel, will never form any part of the evidence arrayed in support of an ice-age man or a paleolithic culture.

Another discovery, to which much attention has been given on account of its supposed bearing upon the paleolithic question, was made in 1889. Mr. W. C. Mills, of Newcomerstown, Tuscarawas county, Ohio, found a single specimen of chipped flint in an exposure of glacial gravel in that place. The specimen fell into the hands of Professor G. F. Wright, by whom it has been widely exhibited and published. A cut of it appeared in his "Man and the Glacial Period," from which work a brief extract may be given in this place. He states that Mr. Mills found this "finely shaped flint implement sixteen feet below the surface of the

[1] Putnam, F. W., 23d and 24th Annual Reports Peabody Museum, p. 94.

terrace of glacial gravel which lines the margin of the Tuscarawas valley. Mr. Mills was not aware of the importance of this discovery until meeting with me some months later, when he described the situation to me, and soon after sent the implement for examination. In company with Judge C. C. Baldwin, President of the Western Reserve Historical Society, and several others, a visit was made to Mr. Mills, and we carefully examined the gravel-pit in which the implement occurred, and collected evidence which was abundant to corroborate all his statements. The implement in question is made from a peculiar flint which is found in the Lower Mercer limestone, of which there are outcrops a few miles distant; and it resembles in so many ways the typical implements found by Boucher de Perthes, at Abbeville, that, except for the difference in the material from which it is made, it would be impossible to distinguish it from them. The similarity of pattern is too minute to have originated except from imitation."[1]

In another place Dr. Wright gives a statement of Mr. Mills in regard to the specimen, from which I quote the following additional details: "While examining the different strata of the gravel, I found the specimen that you have before you fifteen feet from the surface of the terrace. The bank was almost perpendicular at this time, exposing a front of about twenty feet. The small part of the bank was in place in the side of the terrace, until I struck it with my walking-cane, when a space of about six feet in length by two feet in height tumbled down, exposing to view the specimen. At first I recognized the peculiar shape and glossy appearance of the specimen, such as were characteristic of paleolithic specimens described to me by Professor Edward Orton, while I was a student at the Ohio State University."[2] Mr. Mills has, I believe, published nothing save through Professor Wright, and we must therefore take the above as the authoritative statements of the finding. A re-statement embodying additional minor details and placing the evidence fully and

[1] Wright, G. F. "Man and the Glacial Period," p. 251.

[2] Wright, G. F. Report of Western Reserve Historical Society, Dec. 12, 1890.

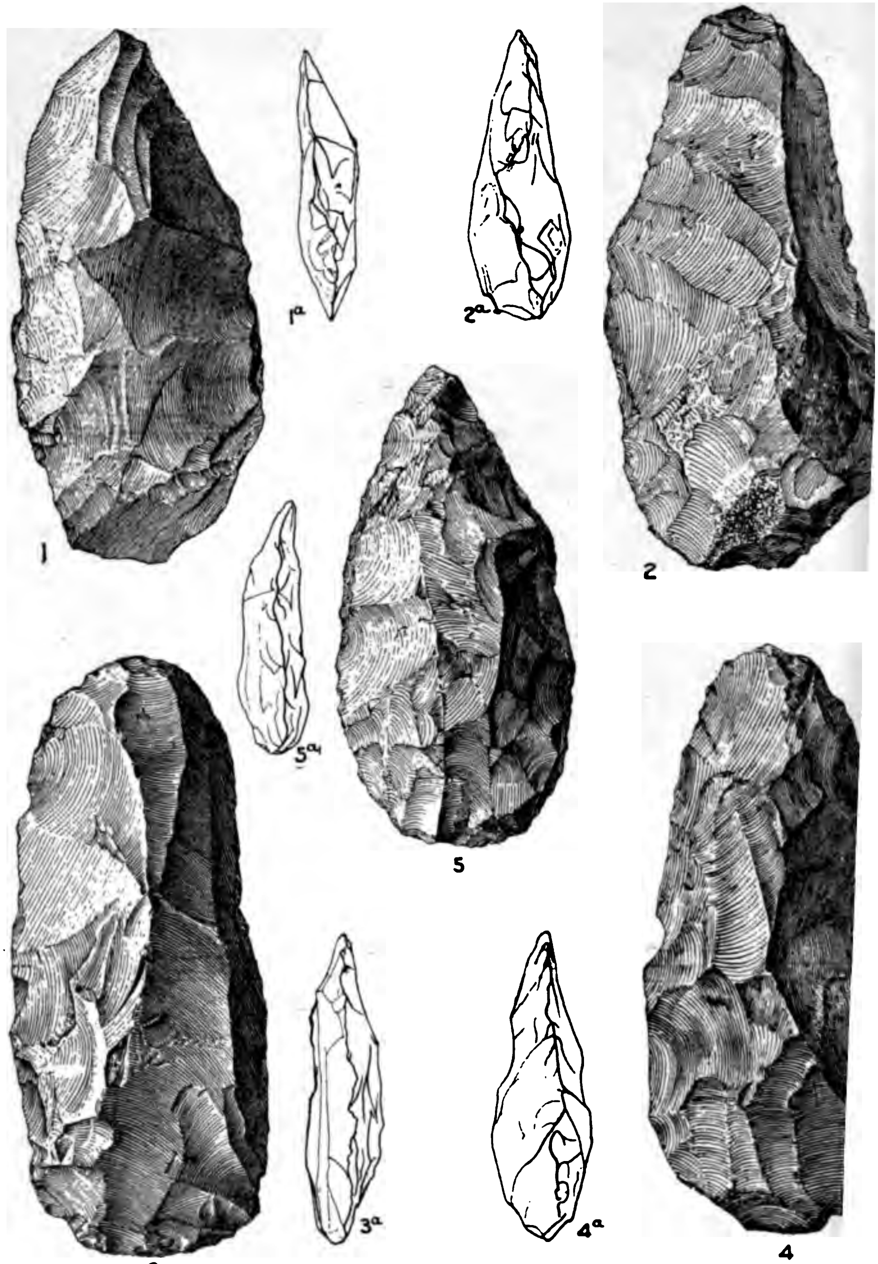


Plate illustrating the Newcomerstown " paleolith," copied with all possible care from the cut in " M
and the Glacial Period," and four ordinary rejects of the blade-maker, the latter obtained in three cas
from modern flint shops in the same region, and in the fourth case directly traceable to the same shop
The separation of the " implement " of glacial age and paleolithic type from the modern rejects is left
the reader. Three-fourths actual size; the profiles on a still smaller scale.

finally upon record, an excellent thing to do, appeared in *Science* for February 3, 1893.

The question may now be raised as to the value to be attached to this find, since the observation is one upon which much is made to depend. In September, 1892, I visited Newcomerstown and examined the site of the discovery of this interesting object, which is shown in the accompanying plate. The town is built along the margin and on the slopes of a glacial terrace, formed about the end of a spur of the hills which projects into the valley on the north side of the Tuscarawas. The exposures of the gravels in the railway ballast pit are excellent, showing them to be ordinary irregularly bedded deposits of sand and gravel. It is a sufficiently promising place for the recovery of such implements or objects as the gravels may happen to contain. The formations are very loosely bedded, and it takes but a short time after the desertion of the site by workmen, especially if the weather is wet, to cover the exposures with talus. Large masses are liable to fall, carrying with them all objects resting upon and near the surface. A collector not on his guard, or not appreciating the nature or significance of finds, might readily, when afterwards questioned about the matter, give a faulty diagnosis of the conditions of discovery. The case in hand is one in which double assurance of verity is called for, yet it is one in which uncertainty resulting from the lack of experience and possible, I may say probable, carelessness of the collector is augmented by the treachery of the gravels. This uncertainty is again emphasized by the discovery, made at the time of my visit, that this terrace is probably an old Indian village site, and certainly a shop site where flint was flaked, many rejects and flakes occurring upon the very brink of the pit. Of course I found no duplicate of the specimen in question, for duplicates are *raræ aves*; but I saw enough to convince me of the danger of hastily and unqualifiedly making use of the observation made by Mr. Mills, especially since the material of which this object is made occurs in the neighborhood, and must have been used by the Indians inhabiting this site.

There is no doubt that this specimen suggests, perhaps more decidedly than any other American so-called gravel implement thus far collected, a resemblance to one of the well-known European types of implements. This is noted by Professor Wright, and may be regarded by many as a point worthy of attention. We must, however, look with extreme caution upon deductions drawn from or depending upon analogies of form. Close analogies of form between Indian rejects and some varieties of European paleolithic objects are too common to permit the attachment of much value to this feature of this or any other similar find. The remark of Professor Wright quoted above, that "the similarity of pattern is too minute to have originated except from imitation," is rather a novel statement, since no specimen of its type has been reported from the American gravels, and the Newcomerstown man could hardly have been familiar with European forms. The only available models would appear to be the Indian rejects of the valley of the Tuscarawas.

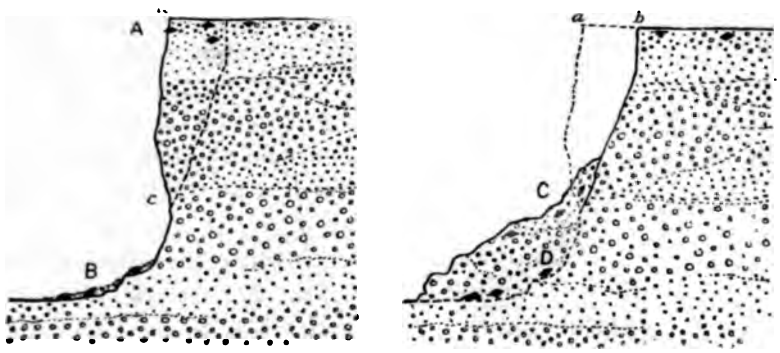
As to the surface polish, that is a common feature of the Ohio flints, and I have before me during this writing a tray of quarry rejects that have the same glazed effect. This is a characteristic of the stone, and has no bearing upon questions of age or use or culture, and must be considered as without significance in these connections.

Professor Wright is entirely satisfied with the results of his efforts to corroborate the statements of the collector. He has examined and reëxamined Mr. Mills, receiving every assurance of the verity of the find, but after all he really secures no additional assurance and can receive no fully satisfactory assurance that Mr. Mills was not in error. Professor Wright has visited and photographed the site and will speedily prepare a plate fo publication,[1] for just what purpose, however, it is rather hard t see, since the nature of the gravels is not disputed, and a volum of photographs will not give additional weight to the proofs. A photograph made of the tree after the bird has flown will no help in determining the bird. No more will observations on M

[1] Wright, G. F., Science, February 3, 1893.

Mills' moral character, his education or business reputation, diminish the danger of error. The specimen may not have been found in place notwithstanding all possible verification, and it may be a reject notwithstanding its resemblance to foreign types, and Professor Wright may be wrong in urging his conclusions upon the public, notwithstanding his painstaking efforts to secure all possible affirmative testimony.

It is nowhere stated that Mr. Mills actually picked the specimen out of the gravels; it was probably loose when he dis-



Figs. 1 and 2. Sections of wall of gravel-pit showing redistribution of surface objects by sliding masses. The dark figures represent objects of art.

covered it, but even if he could say that it was fixed in the gravel mass, the necessity of questioning the find would still exist. All the authentication Professor Wright can possibly secure will not enable him to determine whether Mr. Mills struck with his walking stick a small mass of the gravel in place at a depth of sixteen feet, or whether he was dealing with a mass which had slid with its inclusions of modern relics from the surface to a depth of sixteen feet, as indicated at C, Fig. 2. The object ***may have been*** in place, but can we afford to decide momentous questions upon the evidence furnished by a single specimen obtained under the conditions existing in this case, and by a collector who for months after the finding "was not aware of the importance" of the discovery?

At Warsaw, in Coshocton county, fifty miles west of Newcomerstown I visited an exposure of gravels in a railway cutting, the conditions being almost identical with those at Newcomerstown. The terrace, as in the other case, has been occupied by Indian flint workers, and being in the proximity of extensive flint quarries, there is much refuse of manufacture. I gathered a peck of turtle-backs and rude objects of paleolithic types from the level ground above, and in the wall of the gravel pit found several pieces, descended from the surface, that would be freely admitted into the paleolithic family by its sponsors. Work in the excavation had ceased several months before, and the face of the bluff, nearly thirty feet high and two hundred yards long, was well veneered more or less deeply with talus deposits, through which in places and especially near the top, the normal gravels could be seen. The redistributed deposits along the base of the steep slope were well reset, and from these I obtained a number of flaked flints; several of which were firmly imbedded, and two of them were removed from the gravel with some difficulty and with the aid of a pick, one twenty-five and the other twenty-seven feet beneath the surface of the terrace. The latter specimen is shown in the accompanying plate.

In studying this section at Warsaw I was led to realize the folly of hastily using inexpert evidence regarding the finding of relics of art in gravels. In a case like this even the experienced scientific observer, whose attention had not been definitely called to the nature and far reaching significance of such finds, might from a casual observation have recorded the recovery of one or more of these objects from the gravels. The danger would be greatly increased if the observer were only a relic hunter, or if he were convinced that the gravels at any depth might be expected to contain such objects. These specimens were in the gravels firmly imbedded, and to all appearances this particular portion of the deposit was in a normal condition. Any one could here have dislodged a portion of the mass with his walking-stick with fair prospect of finding a flaked stone of paleolithic type. I doubt very much if we are justified in using the casual obse

vation of an inexpert collector at all in questions where there is no other well-established body of evidence with which to associate it. The function of such data does not extend legitimately beyond the confirming of testimony already well verified.

I present in the accompanying plate examples of the finds from the gravel talus and from the shops above. They correspond very closely in material and appearance with the Newcomerstown specimen, as will be apparent from an examination of the plate. The figures are presented without identification in order that the student may, by an effort to distinguish them, convince himself of the similarity of the supposed paleolith to the quarry-shop rejects of the region. I am not satisfied with the drawing of the former specimen which is a copy, the best that could be made, of the cut published in "Man and the Glacial Period." I desired to have a new drawing direct from the specimens, but a request looking to that end, made to Professor Wright, met with no response.

The four quarry-shop failures here shown are not rare finds with unusually implement-like features. They are everyday rejects, and four hundred could be presented as readily as four.

Summing up the evidence of gravel man in Ohio, assembling all of the finds of several earnest workers these many years—the fulfillment of Professor Wright's prophecy—we have to consider three specimens only. The finding of these objects seems ordinarily well attested, and there is not the least hint of deception or partial withholding of details of discovery. The specimen found by Dr. Metz in his cistern was eight feet deep, and on, or in, the surface of the gravel bed beneath eight feet of silt that may or may not be glacial. Eight feet is not a great depth, however, and we are justified, so long as the specimen stands alone, in expressing our fears that it might, through some unsuspected disturbance of the soil, artificial or natural, have been introduced or covered up to this depth at some date in the long period separating the ice age from the present. A number of agencies known to disturb the soil to considerable depths, are referred to in my paper on early man in Minnesota, in the April

number of *The American Geologist*, and Mr. Frank Leverett, in the March number of that journal, dwells at some length upon this subject. In response to an inquiry, I received the following note from Dr. C. Hart Merriam, the naturalist, on the burrowing of native animals:

"In reply to your inquiry respecting the depth to which our burrowing mammals penetrate, I regret to say that precise information on the subject is somewhat meager. A number of species, such as our woodchucks or marmots, skunks, foxes, coyotes, badgers and prairie dogs live in burrows of greater or less depth which they construct for themselves. In a few instances these burrows are known to extend to a depth of eight feet or more. One of the gophers is said to dig a spiral well fifteen feet deep. Badgers and prairie dogs are notorious diggers, making vast numbers of holes and bringing up immense quantities of material from unknown depths. Their burrows, moreover, are usually very steep, so that a stone or other object falling into one would descend to a considerable distance before being intercepted. Badgers and coyotes make very large holes, though small in comparison with those of the large wolf, which was formerly abundant throughout the Mississippi Valley; the burrows of the latter animal are of sufficient size to readily admit the body of a small boy."

The Loveland specimen was recovered at a great depth beneath the surface but we are bound to raise the queries, Is it an implement? Was it in place; and what is the meaning of the dark soil found on its surface? Of the Newcomerstown specimen it may be said that the collector had little knowledge of the nature of the gravels and of the treacherous character of talus deposits, or of the importance or peculiar bearing of the find. There is, therefore, a most serious possibility of error. There is a decided chance that errors of observation may have crept in in all the cases.

And what is the story of the specimens themselves? The Madisonville object is to all appearances an ordinary reject of the flint-blade maker. It can be practically duplicated upon

almost any quarry-shop site. The pick-like object from Loveland is somewhat unique, and thus has a certain interest of its own, independent of the manner of its finding. At best, however, it was probably not a finished implement at all and there is strong evidence that it has never been used. It may not have more than a remote resemblance to any tool ever employed by the occupants of the valley. The Newcomerstown object appears to have a marked resemblance to certain foreign implements, but the Tuscarawas valley flint-shops furnish many other specimens whose analogies are nearly if not quite as close.

These specimens constitute the Ohio evidence. There is nothing more, for it would be a great mistake to present surface finds as "paleoliths" or as gravel art, no matter how close their resemblance to these or to European forms. It is safest to assign all to the historic Indian save those obtained and proved to have been obtained from the gravels in place.

These three specimens furnish the most satisfactory proofs, so far collected, that a glacial, paleolithic man inhabited the Ohio valley, and upon the evidence of these three slightly shaped stones, obtained from isolated localities, it has been proposed to carry the history of man back some thousands of years farther than can be done by any other means yet discovered.

No careful student will venture to say that the evidence furnished by the three specimens is satisfactory and conclusive. The finds are not demonstrably implements but have the characteristics rather of rejects of manufacture. Their employment as evidence of a *paleolithic stage of culture* serves only to emphasize the utter inadequacy of the available proofs on that point.

Considering the meagre and unsafe nature of these proofs, there seems little doubt that a *glacial man* for the Ohio valley has been somewhat prematurely announced and unduly paraded.

W. H. HOLMES.

THE VOLCANIC ROCKS OF THE ANDES.

THROUGH the excellent work of Dr. Richard Küch,[1] who has recently published the results of his investigation of the rocks collected by Reiss and Stübel in Colombia, we are put in possession of some important conclusions regarding the character of all the volcanic lavas of the South American Andes. Most of these conclusions are pointed out by Dr. Küch in the work cited; to these the present writer wishes to add a few not heretofore noted.

In order to appreciate the value of Küch's work, it should be observed that it was carried on upon the very extensive material collected by Reiss and Stübel during a prolonged exploration of the high mountainous regions of South America, in which they visited Colombia, Ecuador, Bolivia, Peru and Chili and brought away with them 18,000 specimens. In some places as many as 800 were collected, in others much fewer; for, as Reiss observes in the introduction to the volume upon Colombia, many of the mountains are well nigh inaccessible, their bases being covered with dense forest, and their summits hidden beneath snow and glaciers, and shrouded with clouds the greater part of the year. This is equally true of the Cordilleras farther south, so that the exploration of the region is attended with great difficulties. And while it is not claimed that the collections are complete, they must certainly be taken as representatives of the whole of the Andes.

The volcanoes of Colombia chiefly occur along the crest of the central range, rising above crystalline schists, and eruptive masses in the Cretaceous formation, whose upturned strata compose the ranges east and west of the central Cordillera. Heretofore, with few exceptions, the volcanic rocks examined have

[1] W. Reiss and A. Stübel: Reisen in Süd - Amerika. Geologische Studien in der Republik Colombia, I. Petrographie. 1. Die Vulkanischen Gesteine bearbeitet von Richard Küch. Berlin, 1892.

been from the Andes south of the equator. In the present instance our knowledge of them is extended to the most northern end of the great Cordilleran system.

A critical review of all previous work upon the lavas of the Andes, and its comparison with that by himself on the lavas of Colombia, and with a preliminary study of the collections by Reiss and Stübel from Ecuador, led Küch to the conclusion that essentially the same petrographical relations exist at all the volcanoes of the Andes.

With few exceptions all of these recent volcanic lavas of which we have any knowledge, are andesites and dacites, that is, rocks whose essential constituents are soda-lime-feldspar and one or more of the minerals: pyroxene, hornblende and biotite, with which is associated quartz, in the case of dacite. Recent eruptive rocks whose mineral composition falls outside of this group appear to be of rare occurrence, and are rocks closely related to andesite and dacite in composition, namely: quartz-trachyte or rhyolite on the one hand, and basalt on the other. In two instances rocks described as trachyte and quartz-trachyte by Stelzner are shown by Küch to be more properly dacite.

The known occurrences of true basalt are few, the most basic rocks being more closely related to pyroxene-andesite than to basalt, according to Küch's interpretation. Dacite, though seldom mentioned by previous investigators, is of very frequent occurrence judging from the collections by Reiss and Stübel.

The study of such abundant material naturally led Küch to first treat the lavas of Colombia as one general group of intimately connected varieties, without reference to their geographical distribution, for it became evident, as he remarks, that neither a single rock, nor a specially abundant development of any one kind, nor the association of a certain number of different rocks could be considered characteristic of any particular volcano. The same rocks with like multiplicity of development, and the same associations of rocks, repeat themselves in different localities in such a manner that what may seem to be the prevailing or the subordinate varieties in one place are more likely to appear such

because of the greater or less completeness of the material collected, than by reason of their actual scarcity or abundance in nature.

The chief feature of the report consists in the systematic description of the lavas of Colombia based upon their microscopical investigation in conjunction with their chemical analysis. The second part of the report is devoted to a description of the rocks in connection with their geographical distribution. It is to be regretted that the geological relations of the rocks with one another are not furnished at the same time.

The rocks are first discussed from a mineralogical standpoint, their mineral composition and structure being taken as the basis of classification within the general group of extrusive igneous rocks, to which they all belong. They are all embraced within the families of andesite and dacite, as defined by Rosenbusch. They present a chemical series grading from rocks relatively poor in silica and rich in lime and magnesia with sodium considerably in excess of potassium, to those comparatively rich in silica, and poor in lime and magnesia, but with sodium still in excess of potassium. The lower limits approach basalt, and the upper limits border rhyolite.

The same gradual transition exists in the mineralogical composition. At one end are pyroxene-andesites with accessory olivine, the feldspars being rather basic plagioclase. These pass into pyroxene-andesites without olivine, and into hornblende-pyroxene-andesites, and hornblende-andesites, and with increasing amounts of quartz into dacite, or quartz-andesites. In the dacites the feldspars are: plagioclase, approaching albite, and sanidine; while biotite becomes prominent among the ferromagnesian minerals.

In considering the classification of such a series of rocks, since their mode of occurrence is the same throughout, namely, that of lava streams, Küch finds the grounds of classification to be: chemical composition, mineral composition and structure. Of these, chemical composition is undoubtedly that which under like conditions of solidification controls the mineral and structural

development of the rock. Consequently he concludes that upon purely theoretical grounds a chemical classification would be the most desirable. But from the present condition of our knowledge this would be impracticable.

Moreover, he observes, that while the chemical analysis of an unaltered rock furnishes us with the proportions in which the elements existed in the molten magma, it is very probable that rocks of like chemical composition may have been derived from magmas consisting of quite different silicates (that is, possessing different molecular constitutions). And this he suggests is one of the reasons why eruptive rocks with corresponding analyses can exhibit quite different mineralogical compositions. In a foot note he observes that another cause for this phenomenon may lie in differences in the process of solidification, which may affect the rearrangement of the compounds originally in the magma. To this extent the mineralogical composition is dependent on the genesis of eruptive rocks, which he considers essentially the same as their geological mode of occurrence.

Since we are not in a position to infer the original molecular constitution of a magma from its chemical analysis, he does not consider a chemical basis of classification applicable. Nevertheless he states that a comparison of the chemical composition of the andesitic lavas with their mineralogical composition shows that certain differences of chemical composition go hand in hand with others of mineral development, and with these are also connected modifications of structure.

The mineralogical features are the most pronounced, and are therefore selected as a basis of classification. The first subdivision is based on the presence or absence of quartz, and the groups become andesites and dacites. They are not, however, distinctly separated from one another, being connected by gradual transitions. But this grouping, as a purely mineralogical one, fails, as he himself points out, in cases where quartz has not crystallized, as in certain dacitic glasses.

In the further subdivision of these groups the ferromagnesian minerals are employed as distinguishing characteristics, and the

following divisions are established under andesite: Pyroxene-andesite, hornblende-pyroxene-andesite, and hornblende-andesite. Under dacite: Pyroxene-dacite, pyroxene-hornblende-dacite, biotite-hornblende-dacite. As already remarked, the mineralogical gradation from pyroxene-andesite to biotite-hornblende-dacite is by very gradual transitions. Biotite is most abundant in the most silicious varieties.

The microscopical character and the distribution of the porphyritical minerals and of the groundmass, and the relation between the microstructure of the latter and the composition of the rocks are described in detail, and appear to be identical with those existing in the andesites and dacites of western North America. These descriptions are presented in the most satisfactory manner, but need no special notice except to call attention to the occurrence of microlites of quartz in the form of minute pyramids .003 $^{\text{mm.}}$ in diameter, which are an essential component of the glassy groundmasses of numerous dacites. Precisely similar microlites of quartz have been observed by the present writer in certain silicious glasses in the Yellowstone National Park, the descriptions of which have not yet been published.

The chemical composition of the rocks is shown by fifteen complete analyses and ten silica determinations. They range from 54.21 per cent. of silica to 70.22 per cent. The analyses were made from perfectly fresh and unaltered rocks, and the high percentage of water found in some cases, which reaches 3.62 per cent., is referred to the glass base. This is sometimes markedly pearlitic and hydrated. The variations in the proportions of the chemical components throughout the rock series is pointed out, and is correlated with the variations in the minera constituents.

Attention is called to the fact that a frequent mode of altera tion among these lavas leads to the development of opal, an the consequent increase in the silica percentage, so that determination of the silica in a rock may be misleading unles the rock is known to be unaltered.

Dr. Küch's report is to be commended, not only for its scientific excellencies, but also for the form in which it has been published, and the admirable indices which render its details easily accessible.

The facts brought out by this report lead the present writer to certain conclusions regarding the nature of the volcanic ejections of the South American Andes of the greatest importance, which, however, may be modified as our information becomes more complete. In brief, it appears that the main mass of the lavas of all the volcanoes of the Andes is andesite, of variable composition in all localities. It grades into basic varieties, approaching basalt, in some places, and into acid varieties which are dacites, in others. It is probable that the basic varieties would be classed as basalts by many petrologists, but they would not constitute the more basic forms of basalt. The variability in composition and petrographical characters within these limits is pronounced, and proves the intimate relationship between all of the lavas. The almost universal absence of the most basic and most acid members of the series which occur in other regions, namely, the true basalts and rhyolites, is most significant, and, if established by future investigation, would indicate that volcanic activity in the Andes, which is still in force, had developed, by the differentiation of some magma common to the whole great Cordilleran system, a series of lavas of limited range. This series, though precisely similar to parts of others developed in other regions, especially those of Tertiary age in western North America, is wanting in the extreme forms of differentiation common to the latter—that is, in basic basalt and rhyolite. From this we may infer that the general differentiation of the magma supplying the lavas of the Andes has not reached its final stages, in which great volumes of extremely differentiated material will have been developed. It would seem to be in a much less advanced condition than the magmas supplying the lavas in Central America and Mexico, which are in turn less advanced than those of the United States, where volcanic activity is extinct or at least quiescent.

It is not to be expected that all of the volcanoes of the Andes are in exactly the same phase of differentiation, which they undoubtedly are not, but in a general way they have not progressed beyond the limits of olivine-bearing pyroxine-andesite and dacite, and may be considered as having the basalt and rhyolite phases before them. They thus show themselves as comparatively young, or perhaps middle-aged. It will be observed, however, that rhyolite occurs in small amount in Ecuador, as shown by analyses 14 and 15 in Table II.

The chemical similarity of the magmas of the Andes with those of general occurrence in western North America, which are fairly represented by the volcanic rocks of the Yellowstone National Park, is seen upon constructing a diagram of the molecular variation of the essential constituents in a manner employed by the writer[1] and also by Dakyns and Teall[2] in discussing the differentiation of molten magmas.

In Table I are given the chemical analyses of perfectly fresh rocks from Colombia, published by Dr. Küch. The general molecular character of the magmas is shown by diagram I. In the lowest part of the diagram the molecular variation of all of the essential constituents is represented, that of silica being given by the abscissas, the zero point being some distance to the left. In the middle part of the diagram alumina, soda and potash are separated from the lime, magnesia and iron-oxide, which are given by themselves in the uppermost part of the diagram, in order to avoid the confusion of lines in the lowest part. The iron is represented as ferrous oxide. The character of this diagram is quite similar to that of the diagrams for the rocks from the Yellowstone National Park in the paper on the origin of

[1] Iddings (J. P.). The mineral composition and geological occurrence of certain igneous rocks in the Yellowstone National Park. Bull. Phil. Soc., Washington, 8vo. Washington, 1890. Vol. 11, pp. 191–220.

——. The origin of igneous rocks. Bull. Phil. Soc., Washington. 8vo, Washington, 1892. Vol. 12, pp. 89–214, Pl. 2.

[2] Dakyns (J. R.) and Teall (J. J. H.). On the plutonic rocks of Garabal Hill and Meall Braec. Quart. Journ. Geol. Soc. 8vo. London, 1892, May 2, Vol. 48, part 2, No. 190, pp. 104–120.

TABLE I.

CHEMICAL ANALYSES OF VOLCANIC LAVAS FROM COLOMBIA.

	1.	2.	3.	4.	5.	6.	7.	8.	9.	10.	11.	12.	13.	14.	15.
SiO_2	56.91 .948	57.24 .954	59.13 .985	60.05 1.000	61.04 1.017	61.09 1.018	61.26 1.021	63.36 1.056	63.50 1.058	63.56 1.059	65.39 1.089	66.03 1.100	67.30 1.121	68.41 1.140	69.56 1.159
TiO_2				.85	.45	.95				.95					
Al_2O_3	18.18 .178	18.02 .176	17.00 .166	15.59 .152	15.72 .154	15.96 .156	16.15 .158	16.35 .160	15.34 .150	15.43 .151	15.49 .151	14.57 .142	17.55 .172	16.08 .156	15.65 .153
Fe_2O_3	4.65 .029	3.46 .021	7.03	6.95 .043	5.03 .031	4.29 .026	4.39 .027	2.12 .013	3.22 .020	3.02 .018	2.80 .017	2.57 .016	1.47 .009	2.12 .013	1.24 .007
FeO	3.61 .050	4.13 .057		.65 .009	2.15 .029	2.03 .028	2.66 .037	3.05 .042	1.71 .023	2.43 .033	1.99 .027	1.19 .016	1.67 .023	1.44 .020	.91 .011
MgO	3.49 .087	3.77 .094		3.61 .090	3.61 .090	1.06 .026	2.91 .073	3.28 .082	2.50 .062	2.55 .064	2.06 .051	1.89 .047	1.04 .026	1.14 .028	.82 .020
CaO	7.11 .127	7.78 .138	6.67 .119	6.43 .114	5.34 .095	6.66 .115	5.75 .102	4.79 .085	4.31 .077	4.33 .077	4.48 .080	3.38 .060	3.48 .062	3.52 .063	2.52 .045
Na_2O	4.02 .064	5.54	4.80 .077	3.83 .061	4.02 .064	2.89 .046	4.93 .079	3.58 .057	4.84 .078	4.02 .064	4.56 .073	3.71 .059	3.90 .063	4.52 .073	4.09 .066
K_2O	1.61 .017		1.37 .014	1.76 .018	2.66 .028	2.51 .026	2.65 .028	2.92 .031	2.75 .029	2.41 .025	1.59 .016	2.70 .029	2.13 .022	2.24 .023	2.19 .023
P_2O_5	.25			.25		.22		.13		.17	.11	.09	.13		.13
SO_3										.05					
H_2O	.36	.06	.16	.47	.58	1.44	.15	.99	1.99	1.09	.55	2.07	.80	.33	2.92
	100.19	100.00		100.44	100.60	99.10	100.85	100.57	100.16	100.01	99.02	98.20	99.47	99.84	100.03

1. Pyroxene-andesite. N. W. foot of the Purgatorio. Pasto.
2. Olivine-pyroxene-andesite. Pasto.
3. Pyroxene-andesite. Cerro negro de Mayasquer.
4. Pyroxene-andesite. Azufral de Túquerres.
5. Hornblende-andesite. Peñon de Pitayó.
6. Hornblende-andesite. Loma de Ales.
7. Pyroxene-andesite. Lava of 1869. Pasto.
8. Hornblende-pyroxene-dacite, (with olivine and biotite) Cerro negro de Mayasquer.
9. Hornblende-pyroxene-dacite. Chiles.
10. Hornblende-dacite. (With biotite and pyroxene.) Llanos de las Mesas, Tajumbina.
11. Pyroxene-dacite. Cumbal.
12. Hornblende-pyroxene-dacite. Hondon, Chiles.
13. Hornblende-biotite-dacite. Azufral de Túquerres.
14. Hornblende-biotite-dacite. Azufral de Túquerres.
15. Hornblende-biotite-dacite. Loma de Ales.

TABLE II.

Chemical Analyses of Volcanic Rocks of the Andes.

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
SiO_2	52.02	56.50	57.10	58.00	58.35	59.28	60.32	62.35	63.00	63.19	63.49	63.69	66.06	72.46	73.61
	.867	.941	.951	.966	.972	.988	1.005	1.039	1.050	1.050	1.058	1.061	1.101	1.207	1.227
TiO_2						tr				.18					
Al_2O_3	17.14	15.06	17.25	18.00	16.74	18.14	16.92	17.32	18.40	18.65	12.42	15.03	15.64	12.80	12.01
	.168	.147	.169	.176	.164	.177	.165	.169	.180	.183	.121	.147	.153	.125	.117
Fe_2O_3	7.94	} 13.52	} 10.75	3.72			5.88	4.51	3.96	4.01	6.41	2.51		2.32	2.27
	.049			.023			.036	.028	.024	.025	.040	.015		.014	.014
FeO	3.52			2.73	6.71	8.79	1.40			1.89	1.34	2.41	3.90		
	.048			.037	.093	.122	.019			.026	.018	.033	.054		
MnO	.85				.54	tr		.04	.10	.13	.85	.55	.71		
MgO	3.13	2.72	2.50	3.56	4.84	3.43	3.52	3.60	3.71	1.20	1.32	.80	2.57	tr	.20
	.078	.068	.062	.089	.121	.086	.088	.090	.093	.030	.033	.020	.064		.005
CaO	11.57	6.23	5.00	6.96	6.81	4.49	5.64	5.43	5.36	4.86	4.17	3.30	4.53	1.35	.89
	.206	.111	.089	.122	.121	.080	.100	.097	.095	.086	.074	.059	.080	.024	.015
Na_2O	2.38	4.55	5.12	4.36	4.69	4.26	3.83	4.29	4.22	3.69	4.90	6.54	4.00	4.48	4.34
	.038	.073	.082	.070	.075	.068	.061	.069	.068	.059	.079	.105	.064	.072	.070
K_2O	.60	1.35	2.10	2.12	1.18	1.85	2.42	3.13	2.36	1.95	1.78	2.46	2.36	4.11	3.82
	.006	.014	.022	.022	.012	.019	.025	.033	.025	.020	.019	.026	.025	.043	.040
P_2O_5	tr									.15	tr	tr			
H_2O	.28	.30	.25	.32	.31		.44	.13	.36	.07	2.88	2.23	.30	2.92	3.35
	99.45	100.23	100.07	99.77	100.17	100.24	100.37	100.80	101.47	100.07	99.56	99.52	100.09	100.44	100.53

1. Portañuela, Volcano Yate, Southern Chili.
2. Tunguragua, Ecuador.
3. Chimborazo, "
4. Chimborazo, "
5. Tunguragua, "
6. Carahuirazo, "
7. Chimborazo, "
8. Pichincha, "
9. Cachutafruto, Ecuador.
10. Tajumbina, Colombia.
11. Volcano Yate, Southern Chili.
12. Volcano Yate, "
13. Tunguragua, Ecuador.
14. Guamani, Tablon de Itulgache, Ecuador.
15. Oyacachi.

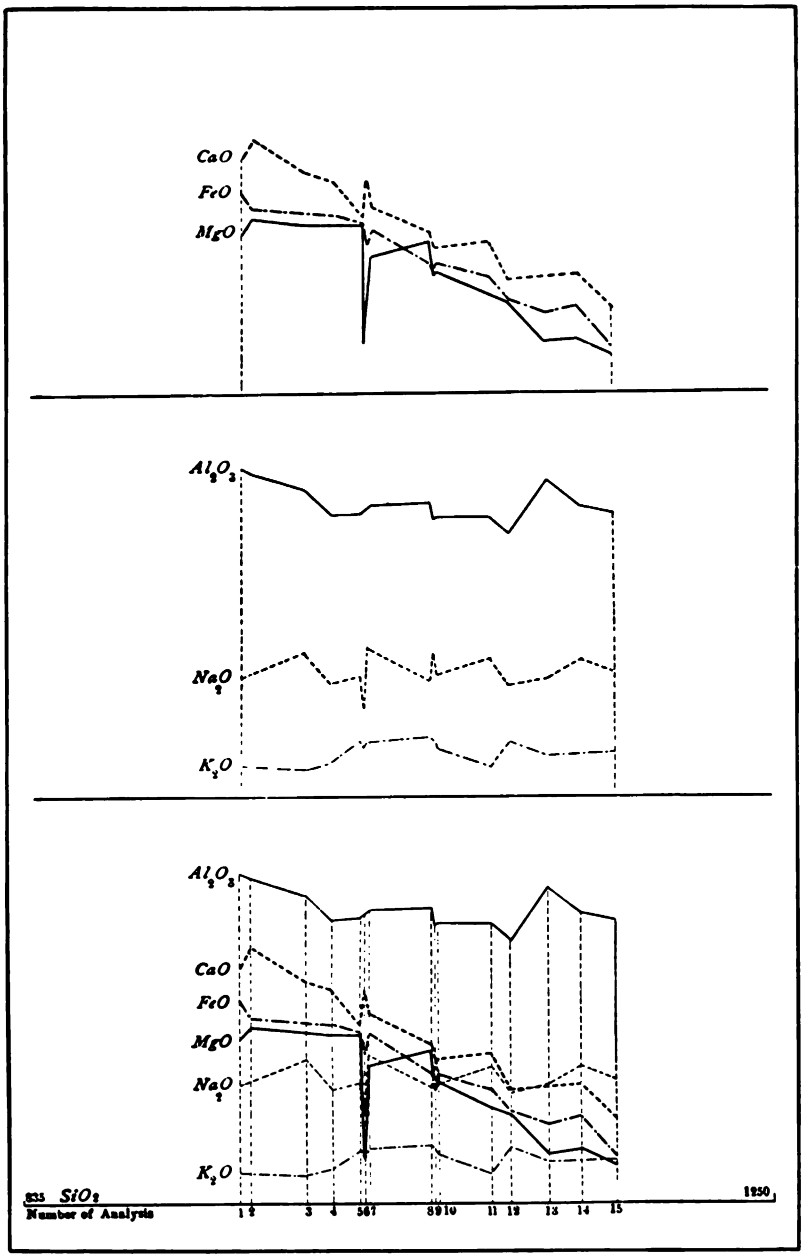


DIAGRAM I.—Molecular variations in lavas of Colombia.

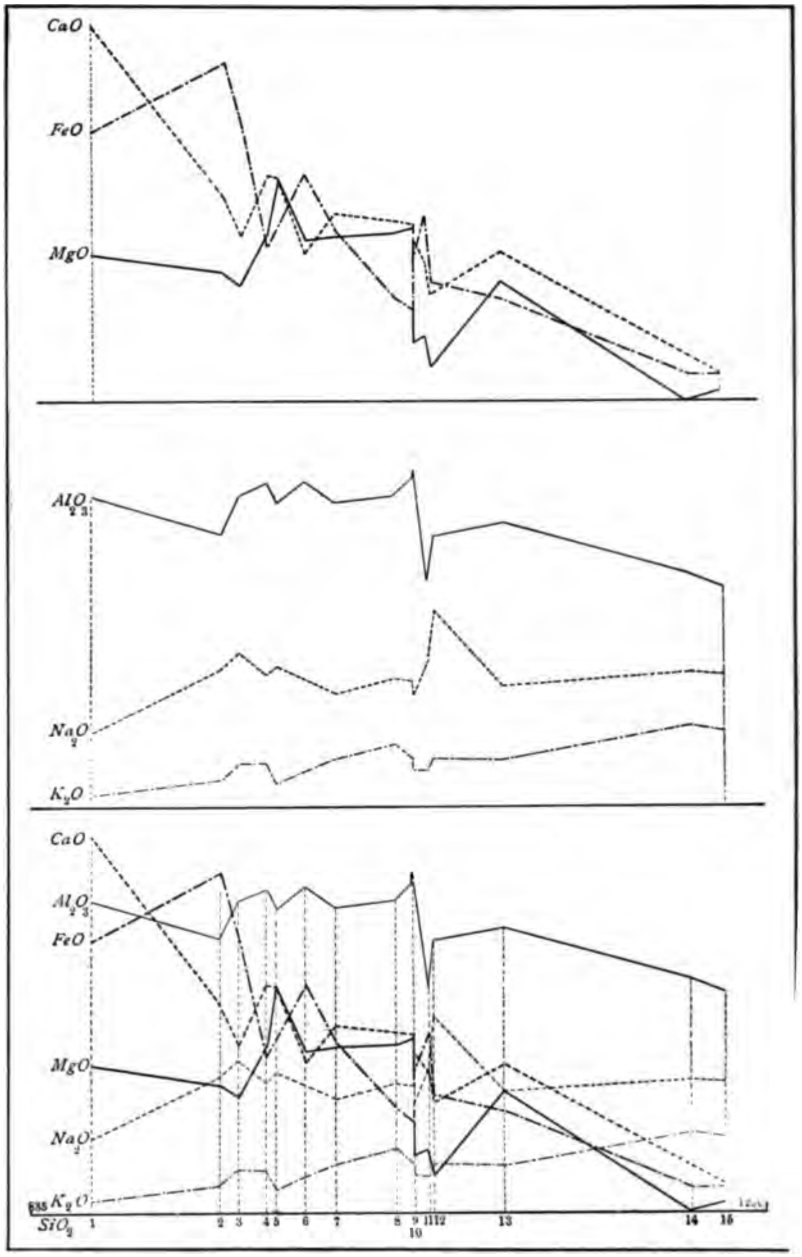


DIAGRAM 2.—Molecular variations in lavas of the Andes.

igneous rocks already cited. There is nearly the same relation between the alkalies and alumina, the soda being still more in excess of potash, and both increasing gradually toward the more silicious end of the series. The alumina maintains a high position, gradually decreasing. The lime, iron-oxide and magnesia decrease rapidly from the less silicious to the more silicious end of the series, and lie somewhat close together. In one instance there is a marked drop in the magnesia.

In Table II are given the analyses of lavas from the Andes south of Colombia, with one exception, as they have been recorded in Roth's tables of rock analyses. They present a somewhat wider range of silica percentages, from 52.02 to 73.61, but whether they have all been made from unaltered rocks is not known to the writer. An analyis of "obsidian" from Colombia is omitted, since it is extremely crude, giving 75 per cent. of silica and 3 per cent. of magnesia, with no lime. Diagram 2 expresses the molecular variations among the rocks included in this grouping. They have the same general nature as those just described, especially as to the alkalies and alumina; but the lime, iron-oxide and magnesia are more variable, which may represent the true condition of the case, or may be due to imperfect methods of analysis.

It is evident from these diagrams that the lavas of the Andes represent various phases of the differentiation of a magma which is chemically similar to that which has furnished the lavas of the Great Basin and extreme western Cordilleras in the United States, and that they belong to similar petrographical provinces.

JOSEPH P. IDDINGS.

ON THE USE OF THE TERMS POIKILITIC AND MICROPOIKILITIC IN PETROGRAPHY.

It is evident that descriptive petrography needs some generally accepted term for both a macroscopic and microscopic rock structure which is, in a certain sense, intermediate between those known as the *granular* or *micrograniti*c and *graphic* or *micropegmatitic*. Areas have been observed and variously described in many types of massive rocks, whose component minerals possess neither the complete independence of optical orientation characteristic of granular structures, nor the entire optical continuity of the separated portions of two interpenetrating crystal individuals. These areas are in fact occupied by a comparatively large individual of one mineral which is more or less completely filled with crystals or grains of other minerals, arranged with no reference to one another or to their host. This structure does not usually appear as distinct from the granular except when seen as a mottling of a large cleavage surface of the enclosing mineral in a hand specimen, or as an irregular spotting of a uniformly extinguishing area under the microscope. In ordinary light, such an area may appear quite granitic, but between crossed nicols it is very distinctive.

Like the graphic or micropegmatitic structure, this relation is most commonly observed between quartz and feldspar especially in the groundmass of quartz-porphyries; but, like that structure, it is also by no means uncommon between many other species.

Essentially this structure was figured and described at length by the writer in a quartz-porphyry from near Tryberg, in the Black Forest, in 1883,[1] although no particular name was at that time given to it. In 1886 the writer proposed the term *poikilitic*

[1] Neues Jahrbuch für Min., etc., Beilage bd. II, p. 607. Plate XII, figs. 3 and 1883.

(ποικίλος, mottled)[1] for the macroscopic equivalent of this structure which is characteristic of the hornblende of the Stony Point hornblende-picrite or cortlandtite, as it is also of the Baste and Schriesheim *schillerfels* of Germany. This had before been called "*luster mottling*," by Pumpelly[2] and Irving,[3] but this name is not capable of application to other allied structures of different appearance. In 1887 the writer described this macro-poikilitic structure in the orthoclase phenocrysts of an orthoclase-norite, belonging to the Cortlandt series.[4]

Though it is not uncommon in many minerals, it is less important and less frequent than the micropoikilitic structure in the groundmass of acid porphyritic rocks of all ages. When studying the ancient quartz-porphyries of Missouri for his thesis, Prof. E. Haworth encountered it and applied to it for the first time the name *poecilitic*.[5] In this connection the writer furnished Dr. Haworth the following from his lecture notes:

"A holocrystalline groundmass contains no amorphous or unindividualized matter whatever, and independently of differences occasioned by variations in the fineness of grain, three quite distinct types of holocrystalline structure are distinguishable. These three types are conditioned by the mutual relation of the quartz and feldspar crystals, which compose the groundmass. In the first place they may be wholly independent, thus giving rise to a granular aggregate which is well designated by the term *Microgranitic Structure*.

"In the second place a granular effect may be produced by the complete interpenetration of two individual crystals of the same size. In this case due to the simultaneous crystallization of the two minerals from the magma - all the parts of the same individual, no matter what the size or shape, must

[1] American Journal of Science (3[d] ser.), vol. 31, p. 30, Jan., 1886. This term was at first incorrectly spelled *poicilitic* and subsequently corrected by Prof. Dana to its Latin form, *poecilitic* (*ib.* vol. 33, p. 139, Feb., 1887). Its preferable orthography is, however, that given above. At the time it was proposed the writer was not familiar with Breithaupt's name, *poikilit*, for bornite, nor with the designations, *terrain poecilien*, *poecilitic* and *poikilitic*, given successively by Brongniart (1829), Conybeare (1832) and Buckland (1837) to the "New Red" sandstone (cf. Bridg. Treat. II., p. 38). The totally different application of these terms could, however, produce no confusion with the one now proposed, even if they were not obsolete.

[2] Proc. Am. Acad., vol. 13, p. 260. Boston, 1878.

[3] Monogr. U. S. Geol. Survey, vol. 5, p. 42, 1883.

[4] American Journal of Science, (3[d] ser.) vol. 33, p. 139, 1887.

[5] Am. Geologist, vol. 1, pp. 368, 369; Pl. I, fig. 1, June, 1888.

have exactly the same optical orientation, and must hence extinguish the light between crossed nicols together. Such a structure is termed, according to the particular form it assumes, *micropegmatitic* or *granophyric*.

"In the third place a single large crystal of one of the two constituents of the groundmass may be filled with much smaller, irregularly arranged grains or crystals of the other. This would also give the general effect of a finely granular structure, although it is essentially different from either of the others above mentioned."[1]

The same structure was briefly described by Teall in a quartz-felsite from the Cheviot Hills, but without any particular designation being applied to it.[2] Harker also mentions a variety of the same structure as common in the ancient rhyolitic lavas of Wales.[3] Cross described the macro-poikilitic structure in a hornblende-peridotite, from Custer county, Colorado,[4] and the micropoikilitic structure in a rhyolite from Silver Cliff in the same district, although the connection between the two was not mentioned. In speaking of the latter rock, he says of the groundmass:

"There seems to be no isotropic matter, but individual characteristics of form and optical action are lost through the minute size of the grains which overlap and overlie each other in the thinnest attainable sections. This mixture is irregular in many cases, but in others a mottled appearance is produced in that one substance attains a uniform optical orientation in certain areas, but is filled by inclusions of the other substance. No regular intergrowth of the two can be discovered. In some spots it was clearly quartz which was the enveloping mineral."[5]

Brögger has described the groundmass of a quartz-porphyry from the region of Christiana as having a typical poikilitic structure.[6]

In his recent monograph on the Eruptive Rocks of Electric Peak and Sepulchre Mountain in the Yellowstone Park, Iddings describes the micropoikilitic structure in the groundmass of certain dike porphyrites, where he for the first time makes use of exactly this term.[7] In speaking of the Sepulchre Mountain dikes

[1] Loc. cit. pp. 367, 368. [2] British Petrography, p. 343. London, 1888.

[3] The Bala Volcanic Series. Cambridge, 1889, pp. 22, 23.

[4] Proc. Colorado Scientific Society, vol. 2, p. 242. 1888.

[5] Ib., p. 232. [6] Zeitsch. für Kryst. u. Min., vol. 16., 1890., p. 46.

[7] Twelfth Ann. Rept. U. S. Geol. Survey, p. 589. 1892.

he calls it a "patchy structure," but says it is identical with what he before called the micropoikilitic (micropoicilitic).[1]

The micropoikilitic structure is extremely abundant in the ancient acid lavas of South Mountain,[2] in southern Pennsylvania and Maryland. It can there be proved in some cases to be of secondary origin as it occurs in plainly devitrified glasses, and it is the writer's opinion that such enclosing quartz areas will, in many cases, prove to have originated subsequent to the solidification of the rock.

I am not aware that either the macro- or micropoikilitic structures have been directly recognized by the German petrographers. I am indebted to Prof. L. V. Pirsson of New Haven for the information that the latter is recognized in France, although we have been unable to find any definition of it in print. He has shown me a section of a quartz-porphyry from Georgia, with a groundmass exactly like those from South Mountain, which Fouqué examined and pronounced an admirable example of the "*type épongeuse*," sometimes called "*structure pétrosiliceuse à ponce*." It is clearly not the same as Michel Lévy's *structure globulaire*, which he defines: "Sphérolites radiés, imprégnés de quartz orienté dans un sens optique unique. Globules imprégnés de quartz orienté, auréoles,"[3] because there the included matter is radially arranged, while in the micropoikilitic structure it is wholly irregular in its arrangement.

The references given above are sufficient to demonstrate the frequency of the rock structure here mentioned, and to show the desirability of some term to describe it. It is therefore proposed that *poikilitic* and *micropoikilitic* be employed for rock structures, whether primary or secondary, conditioned by comparatively large individuals of one mineral enveloping smaller individuals of other minerals, which have no regular arrangement in respect either to one another or to their host.

GEORGE H. WILLIAMS.

[1] Ib., p. 646.

[2] American Journal of Science, (3[d] ser.) vol. 44, p. 482, Dec., 1892.

[3] Roches Éruptives, p. 29. Paris, 1889.

Studies for Students.

THE MAKING OF THE GEOLOGICAL TIME-SCALE.

A CRITICAL examination of the nomenclature applied to the several divisions of the geological scale reveals a strange mixture of names, the reason for which is not evident to modern students of the science. In the list of system-names we find Carboniferous and Cretaceous, indicative of mineral characters, associated with Tertiary and Quaternary, meaning rank in some undefined order of sequence. The presence of these terms is no less mysterious than the absence of grauwacke and old-red sandstone, and primary and secondary, which were originally included. Triassic is the name of another system and records the three-fold division of the system of rocks to which it was applied; and Devonian, the name of another, reminds us of the county in England in which its rocks were first named. Observing these things, one is tempted to call in question the reliability of a systematic classification so heterogeneously compounded.

Although the older living geologists can remember back almost to the beginnings of the science, those who now are beginning their study of geology may find profit in examining the foundation principles, and the systems which have been devised, and have led to the construction and belief in the present classification — a classification, the adoption and unification of which has been thought worthy of the organization and continuance of an international Congress of Geologists. It is needless to call attention to the necessity of some systematic classification of geological formations, but as a foundation for the scientific study of the history of organisms there is need of a time-scale running back into the past, the degree of accuracy of which is known as well as the extent of its unreliability. In early attempts to classify

rocks the chronological element of the scale was not considered, but by degrees the classification has passed from a classification of rocks to a classification of periods of time.

The ancients in many respects were keen observers; they knew much about plants, animals, physical and chemical phenomena, and astronomy. But with all their learning, there appears to have been no conception formed of an ancient history of the globe and its inhabitants prior to the earlier centuries of the Christian era. One of the first geological phenomena to become generalized into a theory was that of the formation of mountains by earthquakes, as cited by Avicenus in the tenth century. The gradual change of relative level of land and sea, as seen in the encroaching of the sea or the departure of sea from the shore, gave rise to speculations regarding the great length of time required for the lifting of the whole land by this means. In the sixteenth century, Lyell reminds us, attention was drawn to the meaning of fossils, and dispute arose as to their nature. Leonardo da Vinci doubted the then current belief that the stars were the cause of the fossil shells and pebbles on the mountain sides, and advanced the idea "that the mud of rivers has covered and penetrated into the interior of fossil shells at the time when these were still at the bottom of the sea near the coast" (Lyell's Principles, p. 34).

By degrees, as Lyell has described in such fascinating manner, one after another the foundation principles arose, were discussed, controverted, and finally, by their intrinsic truth, became established. But it was not till nearly the beginning of the present century that enough was known of rocks for the formation of a general systematic classification of geological formations. The belief in a limit of six thousand years for the formation of the world was prevalent. Catastrophy was the universal resort for explanation of phenomena not then understood. And for geological purposes the Noachian deluge was an indispensable agent for the scientific explanation of even the conspicuous phenomena. For these reasons inquiry did not reach into the antiquity of the geological ages. And the first attempts at classi-

fication took little or no account of actual time-factors in geology.

Lehmann[1] (Johann Gottlob Lehmann died in St. Petersburg, 1767) is generally credited with having first proposed a classification of rocks on the basis of the order of their formation, as Primitive, Secondary, and a third class, the modern or superficial rocks made by the deluge or ordinary river action. Lehmann recognized also a direct relation of origin of the Secondary from the Primitive rocks, and thus arose the beginnings of the geological time-scale. Lehmann recognized three originally distinct kinds of rocks, or rock formations. The volcanic were separated from the others because having no particular connection with either in origin. The distinction, however, between Primitive and Secondary was fundamental. The Primitive was strictly the original, basal rock formed by crystallization from chemical solution before organisms lived; and the Secondary rocks were of secondary origin, made out of fragments of the older and always lying above them. In the original classification of Lehmann, Secondary included all the stratified rocks, as we now consider them, and in the classifications following Lehmann for some years the term Secondary was applied, though in a restricted sense.

Cuvier and Brongniart proposed the name Tertiary for the rocks classified as Secondary by Lehmann, but lying above what is now known as the Cretaceous system; and Quaternary was introduced by Morlot in 1854 for the rocks of superficial position and of glacial or fluviatile origin. Thus the nomenclature of Lehmann, which was proposed originally to indicate the derivation of the Secondary from the Primitive, was expanded on the basis of stratigraphic succession, and we observe the anomaly of a retention of two names (Tertiary and Quaternary), formed on the principle of Lehmann's terms, but his own terms, as well as his theory as a basis of classification, entirely discarded.

[1] J. G. Lehmann, Versuch einer geschichte von floetz-gebürgen, etc., Berlin, 1756. French translation cited by Lyell. Essai d'un Hist. Nat. des Couches de la Terre, 1759. See Lyell, "Principles," Vol. 1, p. 72, and Conybeare and Phillips "Geology," p. vi, and p. xlii.

Werner (1750-1817) elaborated Lehmann's scheme and modified it. He was the great teacher of geology at Freiburg, Germany, in 1815, and left his impress upon the geologists of the time, though he wrote little in the way of systematic exposition of his theories of classification. He adopted Lehmann's *Primitiv Gebirge*, but of the Secondary rocks he made a lower class, which he called transition rocks (*Uebergangsgebirge*), which were stratified, contained none or but few fossils, and were more or less oblique in position; these characteristics were observed in northern Europe, where he studied them. The remainder of the original Secondary rocks, he called *Floetzgebirge*, or flat-lying formations, and these were the equivalents of Lehmann's Secondary in the classification of the early part of the century. Later, the Wernerian school called the formations above the Cretaceous *neues Floetzgebirge*, to which, as they were studied in the Paris basin, Cuvier and Brongniart, in the latter decade of the last century, applied the name *Tertiary*, which still remains in the scheme. Werner called the looser, overlying, unconsolidated rocks *angeschwempt Gebirge*, or alluvial formations, which were afterwards, as above stated, called Quaternary by Morlot.

The classification of Lehmann, as perfected by Werner, was then as follows:

German names.	*English equivalents.*
IV. Angeschwempt gebirge,	Alluvial formations.
III. *b.* Neues Floetzgebirge,	Tertiary "
a. Floetzgebirge,	Secondary "
II. Uebergangsgebirge	Transition "
I. Urgebirge	Primitive "

These were the formations which made up the geological series as then recognized. Volcanic rocks were looked upon as local formations, and of small account in general classification. But they came to be more deeply studied by Werner, and his notion that trap was of aqueous origin led to much controversy, and gave chief prominence to his views (the Neptunian theory) and to that classification of rocks which will be next considered.

The rocks of igneous origin, although sometimes interstratified with sedimentary rocks, do not enter into the present geological time-scale, and for the present purpose further consideration of their classification is unnecessary. There has always been a remnant of rocks at the base of the scale, the consideration of which may be discarded here, because it is known chronologically only as below those rocks of which distinct evidence of their relative age is apparent. The name Primitive has been changed to Primary, and finally to Archæan, a name which was proposed by Dana, and is likely to be retained for some of the basal part of the series.

This first comprehensive classification of rocks may be called the Lehmann classification. It was based upon a structural analysis of the rocks in the order of their actual positions. The nomenclature is applied on the theory of relative order of formation.

Richard Kirwan (Geological Essays, London, 1799), claimed to be the first author to publish a general treatise on Geology in the English language. Although the book is written in a decidedly controversial spirit, the author appears to have had a thorough acquaintance with the various treatises in French, German, Latin and English, in which were expressed contemporaneous opinions regarding geological science. He was a Fellow of the Royal Societies of London and Edinburgh, member of the Royal Irish Academy, and of Academies in Stockholm, Upsala, Berlin, Manchester and Philadelphia, and Inspector General of his majesty's mines in the Kingdom of Ireland. It is probable, therefore, that he presents a fair idea of the opinions which underlay the Lehmann classification. According to Kirwan's book the rocks were originally in a soft or liquid state, the center of the earth was supposed to be hollow, or the whole earth was a solid exterior crust with immense empty caverns within. The materials of the earth were then in a state of fusion or solution, and by condensation, as time progressed, the solids were crystallized out and deposited from the chaotic fluid. The water contracted the surface and lowered upon it by sinking into the interior cavities. With the deposition of the primitive rocks

from the chaotic fluid, the water became purer. Mountains were conceived of as the local points of original crystallization which drew to them, in the process, the minerals from the general fluid. As the waters gradually withdrew by evaporation and sinking into the interior caverns, they became clarified and capable of supporting organic life.

Kirwan says (p. 26): "The level of the ancient ocean being lowered to the height of 8,500 or 9,000 feet, then and not before, it began to be peopled with fish." (Under the name fish he included shell-fish, and all other petrifactions). The plains were formed of depositions from the water of argillaceous, siliceous and ferruginous particles, mingled with those derived by erosion from the already protruding mountains. All the rocks above the height mentioned, he observed, quoting from testimony of numerous travelers, are lacking in fossils; even the limestones are crystalline or "primative" limestones and marbles. These observations were cited in refutation of Buffon's "error" in claiming that all limestones were derived from comminuted shells. According to some authorities, primitive mountains should include rocks of even less height than 8,000 feet, and the occasional presence of fossils at a greater elevation was by them accounted for by their transference to that elevation by the deluge. This account of Kirwan's will suggest the way in which the rock formation came at to be first called "*gebirge*," or mountains. Rocks were supposed to lie as they were originally formed, and thus in classifying rocks the larger aggregates were naturally mountain masses. As the conception of movements in the earth's crust with folding and displacement came into the science, the idea of classification and grouping of rocks was retained, but that their grouping was based upon present massing above the surface as mountains ceased to be accepted as truth. In the German language the term "*Gebirge*" was retained, and apparently with restricted meaning. Kirwan apparently translated the term directly into English as mountains. *Formation* however took the place of *mountain*, as applied to rock classification, in the early part of the century.

Lehmann's classification, in so far as it goes, expressed established facts of nature. There are Primitive, Secondary, Tertiary and Quaternary formations, but the theory that they may be defined and determined by physical structure and present relative position is only approximately true. All crystalline rocks are not primitive, all the secondary rocks are not merely consolidated fragments of primitive rocks. Some of them are fully metamorphosed. All Tertiary rocks are not unconsolidated, as the Tertiaries of California illustrate, and we now know that altitude above the sea, or relative position of the various formations, are by no means uniform and form no criterion for their determination.

The next important advance in the classification of rocks was started by Werner and his pupils. It was a classification based upon the mineral constitution of the rocks. As the study of geology advanced Lehmann's classification was found difficult to apply with precision, and it was found to be unnatural in that rocks of apparently similar kind were dissociated, while rocks of unlike character were brought into the same class. And the mineral character and composition of rocks was found to be an accurate means of defining them. As the mineral characters became clearly understood, the rock masses received their names from the chief minerals in them, and finally the mineral nomenclature entirely superseded the nomenclature of Lehmann, and a second classification arose in which the theory of the original order of formation of the rocks gave place to the actual sequence of mineral aggregates, one after another, in examined sections of the earth's crust. In this study of minerals Werner was a conspicuous leader, and the classifications at the beginning of the present century were mainly his or adaptations of them. The form which the geological scale assumed in English geological systems is seen in typical form in Conybeare and Phillip's Geology of England and Wales, 1822.

Arranged in order from above downwards, it is as follows :

I. *Superior order.* (Neues Floetzgebirge, of Werner).

II. *Supermedial order.* (Floetzgebirge, "

(1) Chalk formation.
(2) Ferruginous sands.
(3) Oölitic system or series.
(4) { Red marle or New Red sandstone.
Newer Magnesian or conglomerate limestone.

III. *Medial, or Carboniferous order.*
(1) Coal measures.
(2) Millstone, grit and shales.
(3) Mountain limestone.
(4) Old Red sandstone.

De la Beche (Geology, 3d edition, 1833) carries out the system more completely, calling the first, or superior order, *Supercretaceous group*, and applying the terms *Cretaceous*, *Oölitic* and *Red sandstone* to three groups into which he divides the second order, and giving the third the name *Carboniferous group*. Below these he recognizes Werner's Grauwacke group, for what was the lower part of the original *Uebergangsgebirge* of his earlier classification, and below this were the *inferior stratified or non-fossiliferous rocks, and the unstratified rocks*. All of the names, it will be observed, are names indicative of mineral characters. If we turn back to the year 1817 we find the same Wernerian system applied to the classification of North American rocks by William Maclure (Observations on the Geology of the United States of America, Philadelphia, 1817). The author writes: "Necessity dictates the adoption of some system so far as respects the classification and arrangement of names. The Wernerian seems to be the most suitable, first, because it is the most perfect and extensive in its general outlines; and secondly, the nature and relative situation of the minerals in the United States, whilst they are certainly the most extensive of any field yet examined, may perhaps be found the most correct elucidation of the general accuracy of that theory, so far as respects the relative position of the different series of rocks." (Observations, etc., p. 28). The classification there set forth is as follows (in the order from below upwards):

Class I. *Primitive rocks.*

Class II. *Transition rocks*—including (1) transition limestone, (2) transition trap, (3) greywacke, (4) transition flinty slate, (5) transition gypsum.

Class III. *Floetz or secondary rocks*—including (1) old red sandstone, (2) 1st floetz limestone, (3) 1st floetz gypsum, (4) 2d variegated sandstone, (5) 2d floetz gypsum, (6) 2d floetz limestone, (7) 3d floetz sandstone, (8) rock salt formation, (9) chalk formation, (10) floetz trap formation, (11) independent coal formation, (12) newest floetz trap formation.

Class IV. *Alluvial rocks*—including (1) peat, (2) sand and gravel, (3) loam, (4) bog iron ore, (5) nagel fluh, (6) calc tuff, (7) calc sinter.

Notice in this classification that the "coal formation" is placed near the top of the secondary rocks, the "rock salt formation" near its middle, and the "old red sandstone" at its base. Later investigations did not confirm Maclure's opinion of the accuracy of Werner's system as applied to American rocks. Amos Eaton's classification of New York rocks (as exhibited in his "Geological and Agricultural Survey of the district adjoining the Erie Canal in the State of New York, Albany, 1824) is an elaboration of the same system.

In each of these classifications, except in a few cases of the retention of distinctions based upon the structural analysis, the whole nomenclature and classification is based upon mineralogical composition of the rocks. In the succeeding progress of the science a great part of the nomenclature has been replaced by other names composed on a different principle, but many of the divisions here recorded are still retained. This latter fact we may interpret to mean that distinctions based upon mineral or lithological characters are of some real and permanent value in geological classification. The history of development of this system from the first, or Lehmann's system, shows that the linear order of the series of formations in the list is based on the con-

ception of a time-scale, and a natural order of succession of the several formations.

The Wernerian classification in this respect was a correct one for the rocks in Northern Germany for which it was constructed. The English scale expressed the facts of sequence, so far as known, for the English rocks, but the attempt to fit either of them to the facts in North America emphasized their imperfection. The fundamental error in the Wernerian system was the assumption that the scale of Northern Germany was a universal scale, or, expressed in general terms, that the mineralogical constitution of a rock has any necessary relation to its place in the stratigraphical series.

The next step of progress in making the geological time-scale arose from the study of fossils. Fossils had been observed and recognized as organic remains for centuries before Lehmann and Cuvier. Lehmann, and he not the first, observed that Primitive rocks did not contain fossils, while Secondary rocks contained some, and what are now called Tertiary rocks contained them abundantly. But it was not until fossils were closely studied, their characters examined, and the species compared and classified that their importance was realized. Cuvier and Brongniart are generally credited with being the first to establish the scientific importance of fossils. (On the Mineral Geography and Organic Remains of the Neighborhood of Paris, 1808). In 1796 Cuvier had called attention to the fact that elephant bones discovered by him in the Paris basin were different from the bones of living species. In thus drawing a distinction between living and extinct animals, as implying present and past groups of living beings, the foundation was laid, not only of Palæontology, but of the whole field of investigation into the history and evolution of organisms. Cuvier and Brongniart, applying their methods of analysis to the rocks of the Paris basin, succeeded in classifying them into strata, and in defining the separate stratigraphical divisions in terms of the contained fossils. The Paris basin rocks being found to lie above the Cretaceous rocks of France and England, which represent the top member of the

secondary formation of the Lehmann classification, were named Tertiary to indicate their geological importance and their relative position in the geological scale. These naturalists did not, however, perfect the geological classification which their biological studies suggested.

William Smith in England ("Tabular view," 1790, and in unpublished maps and sections of the first and second decades of this century) emphasized the value of fossils as means of identifying strata in different regions, and others had some part in the elaboration of the principle involved, but Lyell more than any one else perfected the scheme of classification of geological formations on the basis of their fossil contents. We find him saying, in the second edition of his Elements of Geology, published in 1841, "When engaged in 1828, in preparing my work on the Principles of Geology, I conceived the idea of classing the whole series of Tertiary strata in four groups, and endeavoring to find characters for each, expressive of their different degrees of affinity to the living fauna" (p. 280). A mathematical comparison was made between the proportionate numbers of recent and of extinct species to the several divisions of the Tertiary rocks of England. The result is given in the following table (copied from his "Elements," 2d Ed., Vol. I, p. 284).

Period.	Locality.	Per Cent. of Recent Species.	Number of fossils compared.
Post-Pliocene,	Freshwater, Thames Valley,	99–100	40
Newer-Pliocene,	Marine Strata near Glasgow,	85– 90	160
Older Pliocene,	Norwich Crag,	60– 70	111
Miocene,	Suffolk, red and coralline crag,	20– 30	450
Eocene,	London and Hampshire,	1– 2	400

In the nomenclature here proposed Eocene is derived from the Greek ηως, dawn, and καίνος, recent; Miocene from μειόν καίνος, less recent; Pliocene from πλειον καίνος, more recent, and the definite meaning of the nomenclature and the classification is to signify that the strata called Eocene contain the first traces of the fauna now living, the Miocene strata a small proportion of the living species, the Pliocene and Post-Pliocene more and still more of the living types, and that the whole of the Tertiary

is distinguished from the Secondary and all older beds by containing some representatives of the faunas now living.

In this earliest attempt to estimate time-relations by biological data, Lyell, as others of his time, considered species to be sharply defined natural groups, and therefore it was that the relations between a fossil fauna and its recent representatives could be expressed in mathematical terms, indicating the number of identical species. The principle underlying the classification, however, was of a deeper nature, and concerned the orderly succession of faunas and floras in time. From the application of this method of time-analysis to the Tertiary beds, it was extended to an analysis of the whole series of geological formations on the basis of their organic remains, and the Lyellian classification took the place of the older Lehmann classification as follows :

In place of	Tertiary	we have	Cainozoic.
"	"	Secondary	"	Mesozoic.
"	"	Transition	"	Palæozoic.
"	"	Primitive	"	Azoic.

This latter classification and nomenclature was gradually built up, and mainly by English Geologists, as the Lehmann and Wernerian classification was largely elaborated by German and French Geologists.

Edward Forbes proposed to divide the known faunas and floras into two great groups, Neozoic (modern) and Palæozoic (ancient). The two terms Palæozoic and Protozoic were proposed about the same time. Palæozoic by Sedgwick, for the formations known to be fossiliferous, extending from his lower Cambrian upwards to include Murchison's Silurian system, and Protozoic was a provisional name proposed for pre-Cambrian rocks which might be found to contain fossils. (Sedgwick, Proc. Geol. Soc., Vol. II, p. 675, London, 1838).

In his Silurian System, Murchison proposed Protozoic in the following words : "For this purpose I venture to suggest the term "Protozoic Rocks," thereby to imply the first or lowest

formations in which animals or vegetables appear." (Murchison, Silurian System, p. 11).

Without entering into the delicate question of apportioning the honors due to each of these great English geologists (see *American Journal of Science*, Vol. xxxix., p. 167, 1890), it may be said that in this early usage of the terms, the distinction between Protozoic and Palæozoic was ideal—and in later developments, Palæozoic has been retained for that lower great division of the scale containing distinct remains of organisms, with the Cambrian system at the bottom. To show the connection with the older nomenclature, it may be noted that Palæozoic is equivalent to Primary fossiliferous, and in this system Azoic was applied to the Primitive rocks of the Lehmann system.

John Phillips, in 1841, proposed to extend the method of classification to the whole geological series, and as his scheme was apparently the first complete classification constructed on this basis, it is offered as it appeared in "Palæozoic fossils of Devon and Cornwall," London, 1841, p. 160 (see also Penny Cyclopædia, articles Geology, Palæozoic Rocks, Saliferous system, etc).

Proposed titles depending on the series of Organic Affinities.			*Ordinary title.*
Cainozoic strata	Upper	=	Pliocene Tertiaries.
	Middle	=	Miocene Tertiaries.
	Lower	=	Eocene Tertiaries.
Mesozoic strata	Upper	=	Cretaceous system.
	Middle	=	Oölitic system.
	Lower	=	New Red formation.
Palæozoic strata	Upper?		Magnesian limestone formation Carboniferous system.
	Middle?		Eifel and South Devon.
	Lower	=	Transition strata. Primary srata.

(The terms are founded on the verb. ζαω or ζωω—to live, com bined with καινος recent, μεσος medial or middle, and παλαιός ancient)

Professor Le Conte has proposed Psychozoic, on the same principle for the latest geological period, in which man has appeared. (See Le Conte, Elements of Geology, New York). Lyell proposed to make, on this basis, a geological time-scale and applied the term Period to each of the several divisions of the scale. Thus we find in his Geology, second edition, published in 1841, a recognition of the time element in classification, without as yet the adoption of the biological nomenclature. He gives a table "Showing the order of superposition, or chronological succession, of the principal European groups of fossiliferous rocks. Under the heading "Periods and Groups" we find the following:

I. Post-Pliocene Period	A. Recent.
	B. Post Pliocene.
II. Tertiary Period	C. Newer Pliocene.
	D. Older Pliocene.
	E. Miocene.
	F. Eocene.
III. Secondary Period	G. Cretaceous group.
	H. Wealden group.
	I. Oölite, or Jura limestone group.
	K. Lias group.
	L. Trias, or New Red sandstone group.
	M. Magnesian limestone group.
	N. Carboniferous group.
	O. Old Red Sandstone, or Devonian group.
IV. Primary fossiliferous Period—	P. Silurian group.
	? Q. Cambrian group.

(Lyell, Elements of Geology, second edition, London, 1841. Vol. ii, p. 178).

Later Lyell adopted the biological nomenclature, and was prominent among geologists in developing and elaborating the idea of the successive appearance of new types of organisms coördinate with the progress of geological time.

One of the fullest elaborations of this biological classification of the geological series to form a time-scale is found in Dana's Manual of Geology. (Manuel of Geology; treating of the principles of the science with special reference to American Geological History, by James D. Dana, 3d ed., New York, 1880.) Here we find the larger divisions called times: I, Archean; II, Palæozoic; III, Mesozoic and IV, Cenozoic times. The Palæozoic time is classified into ages, viz: The age of Invertebrates, the Cambrian and Silurian; the age of Fishes, the Devonian; the age of Coal Plants, the Carboniferous. The Mezozoic is called the age of Reptiles. The Cenozoic time includes the age of mammals and the age of man.

Each of the ages is subdivided into periods and epochs, in which the stratigraphical groups and formations form the basis, and the particular faunas and floras of each constitute the data of determination for the time divisions. Thus the Devonian age includes the following:

Periods.

$$\left.\begin{array}{l}\text{Catskill}\\ \text{Chemung}\\ \text{Hamilton}\\ \text{Corniferous}\end{array}\right\} = \text{Devonian Age;}$$

and, as an example, the Corniferous Period includes the following epochs:

$$\left.\begin{array}{l}\text{Corniferous}\\ \text{Schoharie}\\ \text{Cauda-galli}\end{array}\right\} = \text{Corniferous Period.}$$

The distinctions upon which these subdivisions are made are primarily stratigraphical, and we have still to seek a time-classification on a purely biological basis for the whole geological series.

One of the earliest attempts at systematic classification upon a purely biological basis, was made by Dr. Oppel in classifying the Jurassic formations on the basis of the successive Ammonites characterizing the beds. (A. Oppel, *Die Juraformation, Eng*

lands, Frankreichs und des südwestlichen Deutschlands, 1856–1858). Oppel divided the lower part of the Jurassic system (the Lias) into 14 zones or beds; characterized successively from below upwards by their dominant fossil forms, chiefly ammonites.

Thus the successive zones were those of: 1, *Ammonites planorbis*; 2, *A. angulatus*; 3, *A. Bucklandi*; 4, *Pentacrinus tuberculatus*; 5, *A. obtusus*; 6, *A. oxynotus*; 7, *A. raricostatus*; 8, *A. armatus*; 9, *A. Jamesoni*; 10, *A. ibex*; 11, *A. Davœi*; 12, *A. margaritatus*; 13, *A. spinatus*; 14, *Posidonomya Bronnii*. Later classifications, elaborations or revisions of Oppel's system have been made by Wright, in 1860; Judd, 1875; Tate and Blake, 1876, etc. This method of classification recognized the principle of temporary continuance of species and of associated faunas; and it has been applied with greater or less success all through the geological scale of formations for the definition of the lesser divisions.

As early as 1838 the importance of the biological evidence in determining the time-scale was clearly enunciated by Murchison, who wrote in the introduction to the Silurian System, "that the *zoölogical* contents of rocks, when coupled with their order of superposition, are the only safe criteria of their *age*." (The Silurian System, p. 9).

The making of the geological time-scale has now progressed to the stage when it is pretty clearly seen that the ordinary classification of geological formations, as found in our text-books, includes two distinct series of facts: (1) *geological terranes*, arranged stratigraphically and classified by their positions relative to each other and by their lithological characters; and (2) *chronological time-periods*, which may be locally marked by the stratigraphical division planes, but which depend, fundamentally, upon biological evidence for their interpretation and classification. Gilbert[1] has concisely expressed the important fact of the purely local nature of the division-planes separating the formations stratigraphically into stages, series, systems or groups in

[1] Gilbert, G. K. The work of the International Congress of Geologists. Proc. Am. Ass. Adv. Sc., August, 1887. Vol. xxxvi., p. 191.

the words: "There does not exist a world-wide system nor a world-wide group, but every system and every group is local." "The classification developed in one place is perfectly applicable only there. At a short distance away some of its beds disappear and others are introduced; farther on its stages cannot be recognized; then its series fail and finally its systems and its groups."

If we accept the correctness of this statement, it is evident that geological terranes and the stratigraphical division-planes by which they are marked, although indicative of time succession, present nothing in themselves to indicate the particular place they occupy in a time-scale. Even were the age of a particular stratum in one section accurately determined by other means, there is no stratigraphical or lithological mark upon the rock stratum, by which the corresponding age can be recognized in another section. This is not meant to imply that it is impossible to trace a stratum or formation from one section to another in the same general geological province, for in such case it is a process of tracing with slight interruption the continuity of the one terrane. But when we pass from one basin to another, the physical continuity is broken, and the stratigraphy and lithology were made on a separate basis. Hence we reach the conclusion that the perfecting of the geological time-scale must be wrought by the means, primarily, of organic remains. Chronological time-periods in geology are not only recognized by means of the fossil remains preserved in the strata, but it is to them chiefly that we must look for the determination and classification of the rocks on a time basis.

This principle is clearly enunciated in the rules adopted by the United States Geological Survey for the direction of the survey.[1] "Among the clastic rocks there shall be recognized two classes or divisions, viz: structural divisions and time divisions. "The structural divisions shall be the units of cartography and shall be designated *formations*. Their discriminations shall be based upon the local sequence of rocks, lines of separation being drawn at points in the stratigraphic column where lithologic cha

[1] Report of the Director for the Tenth Annual Report, 1890, pp. 63-65.

acters change." . . . "The time divisions shall be defined primarily by palæontology and secondarily by structure, and they shall be called *periods*" (p. 65). We have thus reached the stage in the making of the geological time-scale in which the ideas of the *geological formation* and the *geological period* have become thoroughly differentiated. The geological period as a time-unit is primarily defined by the characters of the fossil remains in the rock, so that the elaborating further and making more precise of the geological time-scale must come from a direct study of the life history of organisms as recorded in the stratigraphical formations.

H. S. WILLIAMS.

EDITORIALS.

THE publication of Professor Wright's *Man and the Glacial Period* has been the occasion of much discussion concerning some of the questions with which the book deals. The numerous and somewhat elaborate reviews have criticized adversely many points in the volume; and in spite of the fact that Professor Wright has responded to most of the reviews, and in spite of the fact that both reviews and responses have been reviewed with loud professions of disinterested impartiality, it can hardly be claimed that any specific criticism of the book has been really met. The errors which have been pointed out, some of them trivial, many of them fundamental, still remain. The unjust claims and the misrepresentations of the volume deserved the measure of criticism they have received.

It was especially the author's handling of the evidence concerning the sequence of events in the glacial period, and concerning man's antiquity in terms of geology, which occasioned the somewhat prolonged discussion. Professor Wright is certainly entitled to his opinion on both these questions, as on all others. So far as we know, this right has not been disputed. The point of criticism at the outset was that the author did not fairly represent the present state of scientific opinion on these two questions, in a book which especially professed to set forth the present status of the problems with which it dealt. The justice of the criticisms made on this basis can not be questioned. The attitude of the reviewers, or at any rate the attitude of those who called forth the discussion, was not so much that there were two or more glacial epochs, though they indicated that this was their belief, as that the author had failed to adequately present the evidence bearing on the question, and had left the discussion on this point in such shape as to mislead the public, foi

whom the book was professedly written, concerning the real condition of scientific opinion. The attitude of the reviewers who first criticized the work was not that glacial man did not exist, but that the author had failed to represent the present state of scientific opinion on this question, and that existing evidence does not, in the minds of many competent observers, bear out the conclusion which Professor Wright advances, and which he advances as if it were not open to question. Instead of answering or attempting to answer the criticisms passed on the book, the responses to the reviews, and the reviews of the reviews have diverted, or attempted to divert, attention from the real criticisms, to other matters. They have shifted, or attempted to shift, the discussion from the *presentation* of the above questions in the volume under review, to the merits of the questions themselves. Shifted to this basis, the questions at issue are very different from those first raised, and may continue to be discussed long after *Man and the Glacial Period* has ceased to attract attention.

If the discussion is not at an end, it is presumably near it. Incidentally, two questions which had previously been clearly recognized and sharply emphasized by specialists have been brought into greater popular prominence than heretofore. The one question concerns the simplicity *versus* the complexity of the glacial period. The other concerns the nature of the evidence which is to be admitted into court touching the question of man's geological chronology. The first of these questions has been long before the geological world, and little that is new has been added in connection with the recent discussion. What has been said will be likely to stimulate the accumulation and critical consideration of data bearing on the question.

Concerning the question of man's antiquity in terms of geological history, the discussion has for the first time sufficiently emphasized in the popular mind the importance of the most rigid scrutiny of the evidence which claims to mark a definite stage in geological history when man's existence is beyond question. For the first time, the criteria by which such evidence

must be judged, have been widely discussed. These criteria are not new to the specialists who had earlier defined and used them. But not until now had it been so clear to so large an audience that the evidence concerning man's antiquity is primarily geological, and more than this, that it involves some of the nicest and most particular questions with which geologists have to deal. R. D. S.

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THE article of Mr. Leverett in this number gives occasion to invite attention to certain errors that still linger in the literature of the glacial period, and that are occasionally supplemented by new ones of like nature. They grow out of the failure to distinguish between the Champlain depression and the earlier depression during which the main silts of the Mississippi Valley were deposited. A very large mass of evidence has been presented by different investigators under different auspices during the past decade that seems to us to have completely demonstrated a stage of elevation between the time of the main silt depositions associated with the outer tract of drift in the interior basin, and the time of the low-altitude formations of the St. Lawrence basin of which the deposits of the Champlain valley are the type. This stage of elevation embraced some of the most important events of the glacial period. The two stages of depression, we think, have thus been proved to be altogether distinct. In our judgment they were separated by a long interval of time, but it is not important to insist upon this in this connection. The evidences of this elevation between the two stages of depression embrace practically all the great glacial gravel trains of high gradient that are found south of the St. Lawrence basin. The nature and slope of these give clear testimony to the attitude of the land at the time of their formation. It is not asserted that there were not similar trains connected with the early stages of the earlier invasion of the ice, but the evidence on this point is as yet very scant. It certainly does not embrace the well-known high-gradient valley deposits of the interior, for these lie in valleys cut in the earlier drift and are connected with moraines that lie

north of it, except at those points at which the later drift reaches the border of the earlier. The moraines from which these high-gradient trains of gravel take their origin lie between the two areas of depression-deposits, and there is abundant and clear evidence that they were later than the one and earlier than the other. The phenomena connected with the earlier depression should, therefore, be considered quite independently of the Champlain depression. None of the agencies of the later depression can be legitimately appealed to in explaining the formations of the earlier depression. The confusion of the past, which is pardonable, should be eliminated, and further confusion avoided by the recognition of the distinctness of the two depressions.

T. C. C.

ANALYTICAL ABSTRACTS OF CURRENT LITERATURE.[1]

The Age of the Earth, by CLARENCE KING. (American Journal of Science, vol. 45, Jan. 1893, pp. 1–20, with 2 Plates).

The object of Mr. King's paper is to advance the method of determining the earth's age which was employed by Lord Kelvin (Sir William Thomson), and which was based on a consideration of its probable rate of refrigeration, by applying to it new criteria. The criteria are derived from the tidal effective rigidity of the earth, and the further argument for rigidity based upon the periodic variation of latitude, and also from the researches of Dr. Carl Barus upon the latent heat of fusion of the rock diabase, and upon its specific heats when melted and solid, and upon its volume expansion between the solid and melted state. This rock was considered to represent the probable density and composition of the surface .03 or .04 of the earth's radius.

The two principal conditions within the interior of the earth upon which physical state and all purely physical reaction of the specific materials depend, being the distribution from center to surface of pressure and heat, Mr. King points out the relative values of earth-pressures deduced from Laplace's law, and two hypothetical cases of earth-temperatures. These are expressed by a diagram which shows that the temperatures maintain an almost maximum value from within .05 of radius of the surface to the center of the earth, while pressure increases steadily throughout the entire radius. Near the surface the rate of increase of heat is greater than that of pressure, and hence its effect is to overcome the results of pressure. But this relation obtains only for earth-depths of 200 miles for an earth of the Kelvin assumption. Below this the relations are completely reversed.

The results of Barus's researches furnish the means of fixing the melting points of diabase at pressures corresponding to increasing depth within the earth. These points fall in a straight line when plotted on a chart in which the coördinate axes represent temperatures and parts of the earth's radius. By plotting on the same chart curves expressing the temperature gradients of the earth for different assumptions regarding the initial excess of heat and period of cooling, it is possible to determine the extent of the couche which must remain fused in certain cases, and also the temperature gradient at the surface of the

[1]Abstracts in this number are prepared by Joseph P. Iddings, J. A. Bownocker, Henry B. Kummel, Chas. E. Peet.

earth. From a study of these curves Mr. King is led to conclude that in order to satisfy the conditions of tidal effective rigidity there can be no considerable fused couche within the upper .06 of radius. And since for a given initial temperature the temperature gradient decreases as the period of refrigeration lengthens, an excessive period produces too low a gradient at the surface to satisfy observed rates of heat-augmentation.

To meet both these requirements Mr. King selects a gradient which falls below the diabase line of fusion, and emerges at the earth's surface at a rate not less than the mean rate of 64 ft. to 1° F. This corresponds to an initial excess of 1950° C. and a period of 24×10^6 years.

Corrections which should be made to the assumed rate of refrigeration are considered, and found to modify the result but slightly.

In comparing this method of determining the age of the earth with that by Kelvin, based on tidal retardations, King contends that, from abundant geological observation plasticity must be admitted for slow deformations, enormously in excess of the small change of figure which the stress of tidal attraction would produce but for elastic resistance. And although rigidity prevents a sudden tidal deformation of five feet, it does not prevent a slow radial deformation of five miles of the surface matter. Hence it appears that no time measure can be deduced from the supposed fixing of the present ellipticity at some past date.

A very significant comparison of the earth's age is made with that of the sun, which, according to Helmholtz and Kelvin, is 15×10^6 to 20×10^6 years. It is remarked by Newcomb that the period during which the heat received by the earth from the sun has been of a temperature which would permit water to exist in a liquid state upon the earth is probably not more than 10,000,000 years. King calls attention to the fact that all we know of the earlier strata indicates a water mechanism for their deposition, and that the evidences that life was continuous in them necessitates a climate continuously suitable for the circulation of waters. All of this period therefore must have fallen within Newcomb's limits. And the earth's age, about 24,000,000 years, accords with the 15,000,000 or 20,000,000 found for the sun. J. P. I.

The Age of the Earth. By WARREN UPHAM. (American Journal of Science, March, 1893).

Mr. Upham reviews the estimates which have been made concerning the age of the earth. These range from 10,000,000 to 14,000,000,000 years. The most reliable means, the writer argues, for estimating the age of the earth is through comparing the present rate of denudation of continental areas with the greatest determined thickness of the strata referable to the successive time divisions. He assumes the rate adopted by Wallace of a continental reduction of one foot in 3000 years. Taking Houghton's estimate

for the thickness of the stratified rocks (177,200 ft.), the time required for their formation, he finds to be 28,000,000 years. Mr. Upham next assumes the thickness of the stratified rocks to be 50 miles, and the rate of land denudation to be one foot in 6000 years. This requires 84,000,000 years for their deposition. Estimates of the relative length of geological time divisions are taken from Dana, Winchell and Davis. Estimating the time since the glacial epoch to be 8000 years, the writer concludes from Davis's ratios that from 16,000,000 to 40,000,000 years have passed since life first appeared on the globe. From changes in the floras and faunas since the beginning of the tertiary, Mr. Upham thinks the length of Cenozoic time is about 3,000,000 years. Applying this to Dana's and Winchell's ratios, he concludes that about 48,000,000 years have passed since the beginning of Cambrian time. "But," says Mr. Upham, "the diversified types of animal life in the earliest Cambrian faunas surely imply a long antecedent time for their development, on the assumption that the Creator worked before then as during the subsequent ages in the evolution of all living creatures. According to these ratios, therefore, the time needed for the deposition of the earth's stratified rocks and the unfolding of its plant and animal life must be about a hundred million years." J. A. B.

Continental Problems. ANNUAL ADDRESS BY THE PRESIDENT, G. K. GILBERT. (Bulletin of the Geological Society of America. Vol. 4, pp. 179–190).

Two-fifths of the earth's area has a mean altitude of −14,000 feet, the plateau of the deep sea; one-fourth the continental plateau a mean altitude of +1,000 feet; the remaining third includes the intermediate slopes, the areas of extreme depth and areas of extreme height. With the exception of the Antarctic continent, the continental plateau is a continuous area, whereas the plateau of the deep sea is "separated by tracts of moderate depth into three great bodies, coinciding approximately with the Pacific, Atlantic and Indian oceans." The author discusses briefly several of the unsolved continental problems. (1) By some it is suggested that the continental form is maintained by the solidity and consequent rigidity of the earth; by others the materials underlying the continental plateau are supposed to be lighter than those beneath the oceanic plateau. The difference in density is the complement of the difference in volume. In the author's view the weight of opinion and the weight of evidence is with the latter hypothesis (the doctrine of isostacy). Accepting this doctrine, the question is (2) whether the difference in density is due to difference in temperature or difference in composition. To this question no answer can be given at present. (3) For the origin of the continents the author mentions Dana's hypothesis that the continental areas cooled first and the oceanic last. Only negative results were obtained by the

author in examining the configuration of the continental mass in order to see whether it might belt the earth in a great circle. (4) The causes of differential elevation and subsidence within the area of the continental plateau is yet unknown, but in the opinion of American geologists these differential changes of level are conclusive proof that the changes are in the lithosphere and not in the hydrosphere. (5) The doctrine of the permanence of continents is regarded as not yet fully established. (6) The growth of the continents, also, is considered as a question still open to discussion. The author does not think it is fully proved that continental growth has been as steady a process as is generally believed. Most of the evidence appealed to, and the inferences drawn therefrom, concern only the minima of ancient land. The data of unconformities, by which the maxima can alone be determined, are comparatively few, are usually difficult of determination, and therefore have never been fully assembled. Further search ought to be made along these lines before this question can be considered closed.

H. B. K.

Measurement of Geological Time. By T. MELLARD READE, C.E., F.G.S. (The Geological Magazine, March, 1893).

The particles of which the sedimentary rocks are composed have been used again and again in rock building, but were all originally derived from the pre-Cambrian rocks or from igneous rocks of later date. By estimating then the average area of the pre-Cambrian and igneous rocks, the bulk of sedimentary rocks derived from them during Cambrian and post-Cambrian times, and the rate of erosion, calculation may be made of geologic time since the beginning of the Cambrian. The author assumes "for the sake of the calculation," the average area of the pre-Cambrian and igneous rocks to be one-third the whole land area of the globe. The actual bulk of the sediments accumulated since the beginning of the Cambrian is estimated as equal to the present land area two miles thick. The average rate of erosion is taken as one foot in 3000 years. From these estimates the time that has elapsed from the beginning of the Cambrian is in round numbers 95 millions of years. When the enormous length of pre-Cambrian time is added to the above, the estimate is found to agree very closely with that of Sir Archibald Geikie, *i.e.*, 100 to 600 millions years. H. B. K.

Recent Archæological Explorations in the Valley of the Delaware. By CHAS. C. ABBOTT, M.D. (Publications of the University of Pennsylvania).

This work gives the results of the author's recent investigations in the Delaware Valley, principally at two islands near the head of tide water.

Two classes of implements were found; those of argillite and those of jasper and quartz. He concludes that "an argillite-using man wandered far and wide over this country long before the use of jasper and quartz became so universal." The older "fairly well specialized argillite implements" are, in some localities, found in places at higher levels than the jasper and quartz implements, being deposited when the river flowed at higher levels than at present. However, by erosion and weathering, many of the argillite implements have been dislodged and mingled with the jasper implements along the course of the present river. The subject of palæolithic implements in the undisturbed Trenton gravels is not discussed. The burial customs, earth works, stone mounds, village sites and jasper quarries of the later inhabitants of the valley receive consideration. H. B. K.

The Drainage of the Bernese Jura. By AUGUST F. FOERSTE, with a *Supplementary Note on the Drainage of the Pennsylvania Appalachians.* By W. M. DAVIS. (From Proceedings of the Boston Society of Natural History, Vol. XXV, April 6, 1892, pp. 392–420, 2 plates).

The geological history of the Bernese Jura consists of a series of elevations and depressions, from the Triassic up to the time of the folding in late Tertiary time. The folds have a general east-northeast trend, and were formed by pressure exerted from the southeast along the whole line of the Jura folds. The folds are the strongest along the southeastern border, and decrease in altitude northwestward. They have been considerably eroded. Tertiary and Cretaceous strata are removed from the crests and upper flanks of the higher folds. The drainage lines are: (1) Longitudinal synclinal valleys; (2) Occasional shallow longitudinal valleys along the crests of the anticlines, and (3) Transverse valleys across the folds. The origin of these transverse valleys, particularly those of the Suxe and the Birse, is the question especially discussed. 1. The absence of faults at the points where the valleys cross the folds is fatal to the theory of their origin through faults, as held by Thurman. 2. Their origin from fractures, as held by Studer, Jaccard, Reutimeyer and Greppin, is improbable, for the fractures are not frequent in the Jura mountains now. That every gap due to fracture should have become a transverse connecting water channel is improbable. Some would have remained as wind gaps. 3. That they did not originate from outlets of lakes, as suggested by Phillipson, and Noe and Margerie, is manifest from the fact (1) That there were lower points by which the lakes could have been drained; (2) Some of the basins made by the folding have more than one valley cutting through the fold enclosing them. 4. The inconspicuous part played by the lateral streams on the sides of the Jura Mountains is unfavorable to the

theory of the origin of the transverse valleys through backward erosion and tapping, as suggested by Heim. Wind gaps representing the backward erosion in various stages ought to exist all over the Jura Mountains, which is contrary to fact. "This theory is particularly at fault when the strange grouping of the cross valleys along *lines* transverse to the folds is observed." 5. Their origin from superimposition is impossible, as the geological conditions required were evidently never present. 6. Mr. Foerste considers them of antecedent origin, and says: "Although the direct evidence of the progressive erosion of the streams during the rising of the folds is lacking, the systematic arrangement of several series of the transverse valleys in straight lines is strongly suggestive of the antecedent origin of the streams. This and the failure of other explanations to meet the facts are the main support of the theory."

Professor Davis notes the bearing of these conclusions on his assumption that the Appalachian streams were consequent. The consequent origin of the Jura streams was cited in support of this assumption. In view of Mr. Foerste's conclusions, Professor Davis withdraws the assumption that the "Appalachian streams were *necessarily* consequent upon the structure of the mountains when they were young," but still thinks that they *probably* were because the deformation of the Appalachians was so much stronger than that of the Jura. C. E. P.

Deep-Sea Sounding. By CAPTAIN A. S. BARKER, U.S.N. (New York: John Wiley & Sons, 133 pp. 3 maps).

This volume gives a brief account of the work done by U. S. S. Enterprise in deep-sea sounding on a cruise from Norfolk, Va., to China and return. The route taken was *via* Cape de Verde Islands, Cape of Good Hope, along the coast of South Africa, thence to Madagascar, the Comoro Islands and Zanzibar, thence across the Indian Ocean to the straits of Sunda, thence to China. Soundings were taken every 100 miles, and sometimes oftener. On the return voyage a line of soundings was made from Wellington, New Zealand to Magellan Straits, and from Montevideo northward off the east coast of South America, at varying distances, as far north as the Bermudas.

On charts accompanying the volume are recorded the depth of the soundings and data concerning the nature of the material of the sea bottom. The deepest sounding was 4,529 fathoms, made to the north of Porto Rico, the position being within forty miles of the deepest sounding (4,561 fathoms) ever taken in the Atlantic Ocean. Two submarine peaks were discovered in the South Atlantic Ocean about 20° west of Cape Town, at a depth of 731 and 979 fathoms. The materials brought up were corals, sand and shells. About 20° east north-east of Montevideo an extensive sand bank was found at a depth of 390 to 500 fathoms. The text is made up of extracts from the ship's log and the captain's private journal. C. E. P.

Observations and Experiments on the Fluctuations in the Level and Rate of Movement of Ground-water on the Wisconsin Agricultural Experiment Station Farm, and at Whitewater, Wisconsin. By FRANKLIN H. KING, Professor of Agricultural Physics, University of Wisconsin. (Washington, D. C.: U. S. Department of Agriculture, Weather Bureau, Bulletin No. 5. 75 pp. Ill., 6 plates).

This bulletin records observations made on the fluctuations of the underground water level from 1888 to July 1892. For the purpose of these observations forty-six wells, varying in depth from five feet to eighty-four feet, within an area 1,200×1,000 feet were available. There are certain short-period changes in level of the ground-water. (1) Those due to seasonal and annual changes in rainfall. (2) Seasonal and mean annual changes in soil temperature develop fluctuations by modifying the rate of percolation and of underground drainage, the changes in temperature influence the viscosity of liquids, and variations in viscosity affect the flow of water through capillary tubes of the soil. Besides these changes the surface of the ground-water level is subject to many slight oscillations, some of them almost beyond measurement. "Oscillations of atmospheric pressure of almost every character affect the under groundwater surface. The longer period barometic changes associated with cyclones, the shorter period changes which accompany thunder storms, and semi-diurnal barometric changes have their corresponding fluctuations in the ground-water." It was found that in recording the rate of flow of a tile drain, a spring and an artesian well, that all three had fluctuations synchronous with the barometric fluctuations. The magnitude of these influences is so great that Prof. King thinks the change in flow from large subterranean drainage areas can be registered upon many rivers and lakes. "The equilibrium of the water, in the capillary soil spaces above the surface of the ground-water, is so unstable that apparently the slightest cause is sufficient to upset it, causing the water to flow out of the non-capillary spaces, but only to be returned again on a moment's notice." The diurnal changes in soil temperature produce corresponding rises and falls of the water surface; "the passage of a train, even where the water is twenty feet below the surface, causes the non-capillary spaces to fill up and empty again as the weight approaches and recedes." No fluctuations due to lunar or solar tidal disturbances were observed.

C. E. P.

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(*Further acknowledgments of pamphlets already received will be made in the next issue*).

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MALASPINA GLACIER.

INTRODUCTION.

A DEFINITE classification of glaciers does not seem to be practicable, for the reason that various types which may be selected grade one into another through many intermediate forms. It is convenient, however, especially in teaching, to recognize three generic types termed Alpine, Piedmont and Continental glaciers; and a subordinate class designated as Tidewater glaciers, to include those which reach the ocean and give origin to bergs.

Alpine glaciers occur in many mountainous regions and have their type in the Alps where they were first studied. Several divisions dependent upon size have been recognized.

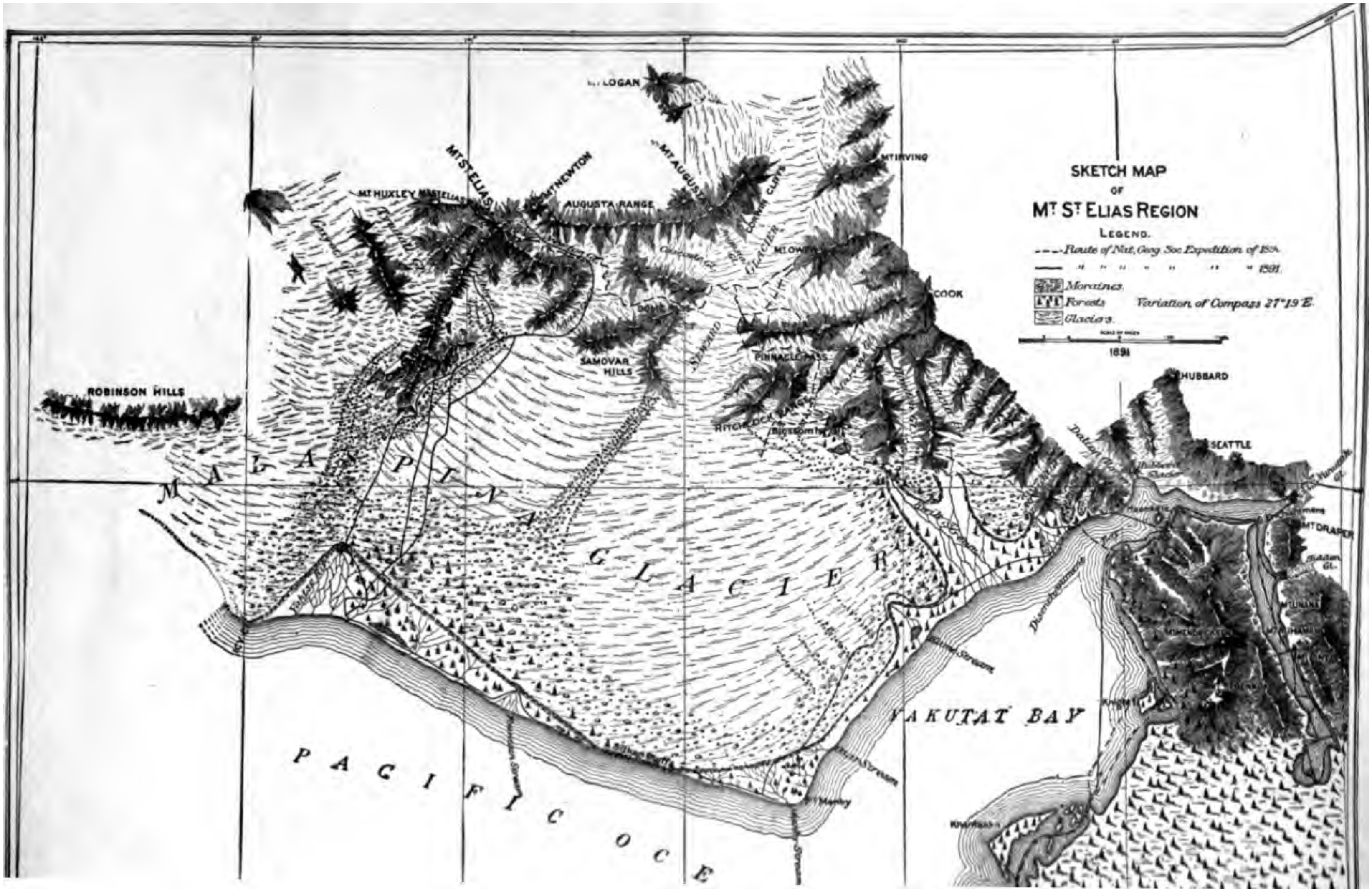
Continental glaciers as their name implies are of vast extent, and at the present time are illustrated by the ice sheets of Greenland and the Antarctic continent. The Pleistocene ice sheets of America and Europe were of this class.

Piedmont glaciers are formed on comparatively level ground at the bases of mountains where the ice is unconfined by highlands in most directions and has freedom to expand. They are fed by glaciers of the Alpine type, which spread out and unite one with another on leaving the valleys through which they descend from snow fields at higher elevations. The only known example of this class occurs in Alaska on the plain intervening between the Mt. St. Elias range and the ocean, and is the subject of this sketch.

GEOGRAPHY OF THE ST. ELIAS REGION.

The south coast of Alaska from Glacier bay on the east to the vicinity of the mouth of Copper river on the west, is bordered by a system of lofty mountains composed of many short ranges, which present steep escarpments to the south and overlook a narrow coastal-plain. At times the plain is wanting as in the vicinity of Mt. Fairweather, and the mountains rise directly from the ocean to great heights. To the north of the uplifts, facing the sea, there is an excessively rugged plateau probably about a hundred miles broad, and with a general elevation of eight or nine thousand feet. On this plateau there are hundreds of short ranges and isolated peaks rising by estimate some five or six thousand feet above the ice-filled valleys, while some of the more prominent summits have a still greater elevation. The northern border of this rugged region has been only partially explored but is known to be less precipitous than its southern face. The elevated region is destitute of both plant and animal life, and is covered with a vast névé field through which many precipitous peaks project. The southern slopes of these islands in the desert of snow are frequently bare in summer and furnish the only relief to the mantle of perpetual white. It is in this region that the ice streams supplying the Malaspina glacier have their sources.

The Tyndall glacier, shown on the accompanying map, is fed by the snow falling on the southwest portion of the Mt. St. Elias range, and flows southward with such a strong current that even after expanding on the plain at the base of the mountains and forming the western lobe of the Malaspina glacier, it continues its southward course and entering the sea forms Icy cape from which thousands of bergs are annually set adrift. Tyndall glacier has important tributaries, especially from the northern side of Robinson hills, but whether it is joined by a glacier from the elevated region to the north of the first range facing the coast, is not known. No break through which a glacier could flow has been observed in the mountain crest to be seen from the ocean, but future explorers may hope to discover such a pass.



SKETCH MAP
OF
Mt St Elias Region
Legend.
Route of Nat. Geog. Soc. Expedition of 18..
" " " " " " 1891.
Moraines.
Forests
Glaciers.
Variation of Compass 27°19' E.
1891
MT LOGAN
MT ST ELIAS
MT HUXLEY
MT NEWTON
AUGUSTA RANGE
MT AUGUSTA
MT IRVING
COOK
HUBBARD
SEATTLE
MT DRAPER
SAMOVAR HILLS
PINNACLE PASS
HITCHCOCK RANGE
ROBINSON HILLS
MALASPINA GLACIER
Seward Glacier
Dalton
YAKUTAT BAY
PACIFIC OCE

The Agassiz glacier is formed by the union of many high-grade ice-streams on the eastern and northern slopes of the St. Elias range, and on the southern face of the equally precipitous Augusta range. All of these tributaries have been seen and are indicated in a rough way on the accompanying map.

Seward glacier is the principal feeder of the Malaspina ice sheet. Its most distant tributaries have their sources far to the north of the Augusta range, in the general névé field covering the main mountain mass. Scores, if not hundreds, of secondary glaciers unite to form the trunk stream which is fully three miles broad where best defined, and probably not less than sixty or seventy-five miles long.

Besides the great glaciers enumerated above there are several smaller ice-streams of the same type, such as the Marvine, Hitchcock, Lucia, etc., each of which is eight or ten miles in length and flows through a deep well-defined valley. Between these various trunk streams there are scores of high-grade glaciers that originate in deep cirques in the southern face of the mountains or in some instances, on the rugged slopes themselves where there are no depressions, and descend to and merge with the vast plateau of ice skirting the ocean.

Before giving special attention to the Malaspina glacier it may be well to glance at a few other geographical conditions which influence its existence.

The climate of southern Alaska adjacent to the coast is mild and uniform. The summers are cool with much fog and rain the winters are not severe, but clear days are rare and snow fall to the depth of several feet. Among the neighboring mountain the snow-fall is excessive and occurs during every month c the year. In the névé region near Mt. St. Elias at an elevatio of about 5,000 ft. it is not uncommon to see strata of compac snow without a parting, fifty feet thick exposed in the walls ‹ crevasses. The mean annual temperature on the coast thought to be about 40-45 deg. F., but this estimate based on observation at a very limited number of station The humidity is excessive, and the mean annual rain-fa

is known to be about an hundred inches. In the vicinity of Mt. St. Elias it is probably even greater than this. The prevailing winds are from the south, at least in summer, and are laden with moisture which is precipitated when the mountains are reached. To the north of the mountains the climate is far different from what it is on the coast. The summers are short and hot and the winters marked by extreme severity; the rainfall is small throughout the year and perennial snow is not seen even on mountains four or five thousand feet high and situated near and even north of the Arctic Circle.

On the mountains facing the ocean the winter snow extends down to sea level but melts during spring and summer so as to form a well defined boundary, or "snow line," which recedes from the coast as the warm season advances. In August and September it has an elevation of about 2,500 feet, corresponding on the glaciers with the lower limit of the névés. The regions below and above the snow line are in marked contrast. From the ocean up to an elevation of from 2,500 to 3,000 feet in summer, every island in the ice as well as the low lands along the coast and even the moraines on the lower border of the Piedmont ice-sheet, are covered with luxuriant vegetation, and are frequently brilliant with banks of flowers. Above the snow line except on occasional sunny slopes at comparatively low elevation, where Alpine flowers thrive, all is desolate, lifeless winter. The well known features characteristic of glacial ice and névé snow are sharply defined by the same horizon. In the higher mountains snow storms are frequent even in summer, and at elevations exceeding about 13,000 feet rain never falls and the snow is fine and dry. On the mountain tops the snow does not soften, even on hot summer days. Its indefinite accumulation is prevented by avalanches and by its being blown away.

The relief of the St. Elias region is due largely to displacements. The mountains are in many instances formed of tilted blocks bounded by faults, and the prevailing structure approaches the Great Basin type. The effects of pre-glacial stream erosion are not distinguishable and in many instances the ice drainage is

consequent upon the prevailing structure. This is shown principally by the fact that large glaciers, such as the Agassiz and Seward, follow lines of displacement; in several instances, cascades occur where glaciers cross faults.

THE PIEDMONT ICE SHEET.[1]

Area.—The Malaspina glacier extends with unbroken continuity from Yakutat bay 70 miles westward, and has an average breadth of between 20 and 25 miles. Its area is approximately 1,500 square miles; or intermediate in extent between the area of the State of Rhode Island and the area of the State of Delaware.

It is a vast, nearly horizontal plateau of ice. The general elevation of its surface at a distance of five or six miles from its outer border is about 1,500 feet. The central portion is free from moraines or dirt of any kind, but is rough and broken by thousands and tens of thousands of crevasses. Its surface, when not concealed by moraines, is broadly undulating, and recalls the appearance of the rolling prairie lands west of the Mississippi. From the higher swells on its surface one may see for many miles in all directions without observing a single object to break the monotony of the frozen plain. So vast is the glacier that, on looking down on it from elevations of two or three thousand feet above its surface, its limits are beyond the reach of vision.

Lobes.—The glacier consists of three principal lobes, each of which is practically the expansion of a large tributary ice stream. The largest has an eastward flow, toward Yakutat bay, and is supplied mainly by the Seward glacier. The next lobe to the west, is the expanded terminus of the Agassiz glacier; its current is toward the southwest. The third great lobe lies between the Chaix and Robinson hills, and its main supply of ice is from the Tyndall and Guyot glaciers. Its central current is south-

[1] This account of the Malaspina glacier has been compiled principally from the proof-sheets of a report by the writer on a second expedition to Mt. St. Elias in 1891, to appear in the Thirteenth Ann. Rep. of the U. S. Geological Survey.

ward. The direction of flow in the several lobes explains the distribution of the moraines about their borders.

The Seward lobe melts away before reaching Yakutat bay and ends with a low frontal slope, but its southern margin has been eaten into by the ocean, so as to form the Sitkagi bluffs. The Agassiz lobe is complete, and is fringed all about its outer border by broad moraines. The Guyot lobe pushes boldly out into the ocean, and breaking off forms magnificent ice cliffs.

Characteristics of the non-moraine-covered surface.—On the north border of the glacier, but below the line of perpetual snow, where the great plateau of ice has a gentle slope, the surface melting gives origin to hundreds of rills and rivulets which course along in channels of clear ice until they meet a crevasse or moulin and plunge down into the body of the glacier to join the drainage beneath. On warm summer days when the sun is well above the horizon the murmur of streams may be heard wherever the ice surface is inclined and not greatly broken, but as soon as the shadows of evening cross the ice fields melting ceases and the silence is unbroken. These streams are always of clear, sparkling water, and it is seldom that their channels contain debris. Where the surface of the glacier is nearly level, and especially when broken by crevasses, surface streams are absent, although the clefts in the ice are frequently filled with water. The moulins in which the larger of the surface streams usually disappear are well-like holes of great depth. They are seldom straight, however, as the water in plunging into them usually strikes the opposite side and causes it to melt away more rapidly than the adjacent surfaces. The water in descending is dashed from side to side and increases their irregularities. A deep roar coming from the hidden chambers to which the moulins lead frequently tells that large bodies of water are rushing along the ice caves beneath. In the southern portion of the glacier, where the ice has been deeply melted, and especially where large crevasses occur, the abandoned tunnels made by englacial streams are sometimes revealed. These tunnels are frequently 10 or 15 feet high, and occasionally one may pass

through them from one depression in the glacier to another. In some instances they are floored with debris, some of which is partially rounded. As melting progresses this material is concentrated at the surface as a moraine.

The ice in the various portions of the glacier was observed to be formed of alternate blue and white bands, as is the rule in glacial ice generally. The blue bands are of compact ice, while the white bands are composed of ice filled with air cavities. The banded structure is usually nearly vertical, but the dip, when noticeable, is northward. Nearly parallel with the blue and white layers, but crossing them at low angles, there are frequently bands of hard, blue ice several hundred feet long and 2 or 3 inches in thickness which have a secondary origin, and are due to the freezing of waters in fissures.

The rapid melting of the surface produces many curious phenomena, which are not peculiar to this glacier, however, but common to many ice bodies below the line of perpetual snow. The long belts of stone and dirt forming the moraines protect the ice beneath from the action of the sun and air, while adjacent surfaces waste away. The result of this differential melting is that the moraines become elevated on ridges of ice. The forms of the ridges vary according to the amount and character of the debris resting upon them. In places they are steep and narrow, and perhaps 150 or 200 feet high. From a little distance they look like solid masses of debris, and resemble great railroad embankments, but on closer examination they are seen to be ridges of ice, covered with a thin sheet of earth and stones. The sides of such ridges are exceedingly difficult to climb, owing to the looseness of the stones, which slide from beneath one's feet and roll down the slopes. The larger bowlders are the first to be dislodged by the melting of the ice, and, rolling down the sides of the ridges, form a belt of coarse debris along their margins. In this way a marked assortment of the debris in reference to size and shape frequently takes place. In time the narrow belts of large bowlders become elevated in their turn and form the crests of secondary ridges. Rocks rolling down the steep slopes are

broken into finer and finer fragments and are reduced in part to the condition of sand and clay. When the debris is sufficiently comminuted it is sometimes carried away by surface streams and washed into crevasses and moulins. Not all of the turbidity of the subglacial streams can be charged to the grinding of the glacier over the rocks on which it rests, as a limited portion of it certainly comes from the crushing of the surface moraines during their frequent changes of position.

Isolated blocks of stone lying on the glacier, when of sufficient size not to be warmed through by the sun's heat in a single day, also protect the ice beneath and retain their position as the adjacent surface melts, so as to rest on pedestals frequently several feet high. These elevated blocks are usually flat, angular masses, sometimes 20 feet or more in diameter. Owing to the greater effect of the sun on the southern side of the columns which support them, the tables are frequently inclined southward, and ultimately slide off their pedestals in that direction. No sooner has a block fallen from its support, however, than the process is again initiated, and it is again left in relief as the adjacent surface melts. The many falls which the larger blocks receive in this manner cause them to become broken, thus illus trating another phase of the process of comminution to which sur face moraines are subjected. On Malaspina glacier the formation of glacial tables is confined to the summer season. In winter the surface of the glacier is snow-covered and differential melting can not be marked. The fact that glacial tables are seldom seen just after the snows of winter disappear suggest that winter melting takes place to some extent, but in a different manner from what it does in the summer. Just how the blocks are dislodged from the pedestals in winter has not been observed.

While large objects lying on the surface of the glacier are elevated on pedestals in the manner just described, smaller ones, as is well known and especially those of dark color, become heated by the sun, and, melting the ice beneath, sink into it. When small stones and dirt are gathered in depressions on the surface of the glacier, or, on a large scale, when moulins

become filled with fine debris and the adjacent surface is lowered by melting, the material thus concentrated acts as do large bowlders, and protects the ice beneath. But as the gravel rises in reference to the adjacent surface, the outer portion rolls down from the pedestal on all sides, and the result is that a sharp cone of ice is formed, having a sheet of gravel and dirt over its surface. These sand cones, as they are called, sometimes attain a height of ten or twelve feet, and form conspicuous and characteristic features of the glaciers over large areas.

The surface of Malaspina glacier over many square miles, where free from moraine, is covered with a coral-like crust which results from the alternate melting and freezing of the surface. The crevasses in this portion of the vast plateau are seldom of large size, and, owing to the melting of their margins, are broad at the surface and contract rapidly downward. They are in fact mere gashes, sometimes ten or twenty feet deep, and are apparently the remnants of larger crevasses formed in the glaciers which flow down from the mountains. Deeper crevasses occur at certain localities about the border of the glacier, where the ice at the margin falls away from the main mass, but these are seldom conspicuous, as the ice in the region where they occur is always heavily covered with debris and the openings become filled with stones and bowlders. The generally level surface of the glacier and the absence of large crevasses indicate that the ground on which it rests is comparatively even. Where the larger of the tributary glaciers join it, however, ice falls occur, caused by steep descents in the ground beneath. These falls are just at the lower limit of perpetual snow and are only fully revealed when melting has reached its maximum and the snows of the winter have not yet begun to accumulate.

Moraines.— From any commanding station overlooking Malaspina glacier one sees that the great central area of clear, white ice is bordered on the south by a broad, dark band formed by bowlders and stones. Outside of this and forming a belt concentric with it is a forest-covered area, in many places four or five miles wide. The forest grows on the moraine, which rests

upon the ice of the glacier. In a general view by far the greater part of the surface of the glacier is seen to be formed of clear ice, but in crossing it one comes first to the forest and moraine-covered border, which, owing to the great obstacles it presents to travel, impresses one as being more extensive than it is in reality.

The moraines not only cover all of the outer border of the glacier, but stream off from the mountain spurs projecting into it on the north. As indicated on the accompanying map, one of these trains starting from a spur of the Samovar hills crosses the entire breadth of the glacier and joins the marginal moraine on its southern border. This long train of stones and bowlders is really a highly compound medial moraine formed at the junction of the expanded extremities of the Seward and Agassiz glaciers.

All of the glaciers which feed the great Piedmont ice-sheet are above the snow line, and the debris they carry only appears at the. surface after the ice descends to the region where the annual waste is in excess of the annual supply. The stones and dirt previously contained in the glacier are then concentrated at the surface owing to the melting of the ice. This is the history of all of the moraines on the glacier. They are formed of the debris brought out of the mountains by the tributary Alpine glacier, and concentrated at the surface by reason of the melting of the ice.

Malaspina glacier in retreating has left irregular hillocks of coarse debris which are now densely forest-covered. These deposits do not form a continuous terminal moraine, however, but a series of irregular ridges and hills having a somewhat common trend. They indicate a slow general retreat without prolonged halts. The heaps of debris left as the ice front retreated have a general parallelism with the present margin of the glacier and are pitted with lake basins, but only their higher portions are exposed above the general sheet of sand and gravel spread out by streams draining the glacier.

The blocks of stone forming the moraines now resting on the

ice are of all sizes up to twenty or thirty feet in diameter, but those of large dimensions are not common. The stones are rough and angular except when composed of material like granite, which on weathering forms oval and rounded boulders of disintegration. So far as has been observed, very few of the stones on the glacier have polished or striated surfaces. The material of which the moraines are composed is of many kinds, but individual ridges frequently consist of fragments of the same variety of rock, the special kind in each case depending on the source of the thread in the great ice current which brought the fragments from the mountains.

In many instances, particularly near the outer border of the ice sheet, there are large quantities of tenacious clay, filled with angular stones, which is so soft, especially during heavy rains, that one may sink waist deep in the treacherous mass. Sometimes blocks of stone a foot or more square float on the liquid mud and lure the unwary traveler to disaster.

On the eastern margin of the ice sheet adjacent to Yakutat bay, where the frontal slope is low, there are broad deposits of sand and well rounded gravel which has been spread out over the ice. On the extreme margin of the glacier this deposit merges with hillocks and irregular knolls of the same kind of material, some of which rise a hundred feet above the nearest exposure of ice and are clothed with dense forests. The debris is so abundant and the ice ends in such a low slope that it is frequently impossible to determine where the glacier actually terminates. The water-worn material here referred to as resting on the glacier, has been brought out of tunnels in the ice, as will be noticed further on.

Surface of the fringing moraines.—A peculiar and interesting feature of the moraine on the stagnant border of Malaspina glacier is furnished by the lakelets that occur everywhere upon it. These are found in great numbers both in the forest-covered moraine and in the outer border of the barren moraine. They are usually rudely circular, and have steep walls of dirty ice which slope toward the water at high angles, but are undercut at the

bottom, so that the basins in vertical cross section have something of an hour-glass form. The walls are frequently from 50 to 100 feet high, with a slope of 40° to 50°, and sometimes are nearly perpendicular. Near the water's edge the banks are undercut so as to leave a ridge projecting over the water. The upper edge of the walls is formed of the sheet of debris which covers the glacier, and the melting of the ice beneath causes this material to roll and slide down the ice slopes and plunge into the waters below. The lakes are usually less than 100 feet in diameter, but larger ones are by no means uncommon, several being observed which were 150 or 200 yards across. Their waters are always turbid owing to the mud which is carried into them by small avalanches and by the rills that trickle from their sides. The rattle of stones falling into them is frequently heard while traveling over the glacier, and is especially noticeable on warm days, when the ice is melting rapidly, but is even more marked during heavy rains. The crater-like walls inclosing the lakes are seldom of uniform height, but frequently rise into pinnacles. Between the pinnacles there are occasionally low saddles, through which in some instances the lakes overflow. Frequently there are two low saddles nearly opposite to each other, which suggests that the lakes were formed by the widening of crevasses. The stones and dirt which fall into them, owing to the melting of the walls, gradually fill their bottoms. Instances are numerous where the waters have escaped through crevasses or openings in the bottom of the basin, leaving an exceedingly rough depression, with a heavy deposit of debris at the bottom.

As the general surface of the glacier is lowered by melting, the partially filled holes gradually disappear and their floors, owing to the deep accumulation of debris on them, which protects the ice from melting, become elevated above the surrounding surface, in the same manner that glacial tables are formed. The debris covering these elevations slides down their sides as melting progresses, and finally a rugged pyramid of ice, covered with a thin coating of debris, occupies the place of the

former lake. These pyramids frequently have a height of 60 or 80 feet, and are sometimes nearly conical in shape. They resemble "sand cones," but are of much greater size and are sheathed with coarser debris. The sand cones are usually, if not always, formed and melted away during a single season, while the debris pyramids require several seasons for their cycle of change.

Like the lakelets to which they owe their origin, the debris pyramids are confined to the stagnant portions of the glacier and play an important part in the breaking up and comminution of the material forming the marginal moraines. Owing to the sliding of the bowlders and stones into the lakelets and their subsequent fall from the sides of the pyramids, they are broken and crushed so that the outer portion of the glacier, where the process has been going on longest, is covered with finer debris and contains more clay and sand than the inner portions.

Just how the holes containing glacial lakelets originate it is difficult to say, but their formation seems to be initiated, as already suggested, by the melting back of the sides of crevasses. Breaks in the general sheet of debris covering the glacier expose the ice beneath to the action of the sun and rain, which causes it to melt and the crevasses to broaden. The openings become partially filled with water and lakelets are formed. The waves wash the debris from the ice about the margin of the lakelets, thus exposing it to the direct attack of the water, which melts it more rapidly than higher portions of the slopes are melted by the sun and rain. It is in this manner that the characteristic hourglass form of the basins originates. The lakelets are confined to the outer or stagnant portion of the glacier, for the reason that motion in the ice would produce crevasses through which the water would escape. Where glacial lakelets occur in great numbers it is evident that the ice must be nearly or quite stationary, otherwise the basins could not exist for a series of years. The lakelets and the pyramids resulting from them are the most characteristic features of the outer border of the glacier. The number of each must be many thousand. They occur not only in the outer portion of the barren moraine, but also throughout

the forest-covered area still nearer the outer margin of the glacier. Large quantities of trees and bushes fall into them with the debris that slides from their sides, and tree trunks, roots and soil, thus become buried in the moraines.

Forests on the moraines.—The outer and consequently older portions of the fringing moraines are covered with vegetation, which in places, particularly near the outer margin of the belt, has all the characteristics of old forests. It consists principally of spruce, alder and cottonwood trees, and a great variety of shrubs, bushes and ferns. In many places the ice beneath the dense forest is not less than a thousand feet thick. The vegetation is confined principally to the border of the Seward lobe. Near Yahtse river the belt is 5 miles broad, but decreases toward the east, and is absent at the Sitkagi bluffs, where the glacier is being eaten away by the sea. It is only on the stagnant borders of the ice sheet that forests occur. Both glacial lakelets and forests on the moraines are absent where the ice has motion. The forest-covered portion is by estimate between 20 and 25 square miles in area.

Outer margin.—The southern margin of Malaspina glacier, between the Yahtse and Point Manby, is abrupt and forms a bluff that varies in height from 140 to 300 feet or more. The bluff is so steep in most places and is so heavily incumbered with fallen trees and boulders, that it is with difficulty one can climb it. Many times the trouble in ascending is increased by land slides which have piled the superficial material in confused heaps, and in other instances the melting of the ice beneath the vegetation has left concealed pit-falls into which one may drop without warning. The bluff formed by the margin of the glacier when not washed by the sea, is boldest and steepest where the covering of vegetation is most dense. Where the covering consists of stones and dirt without vegetation, however, the margin may still be bold. This is illustrated between the mouth of the Yahtse and Icy cape, where the ice is concealed beneath a general sheet of debris, but has a bold convex margin which rises abruptly from the desolate torrent-swept waste at its base.

When the glacier meets the sea the ice is cut away at the water-level, and blocks fall from above, leaving perpendicular cliffs of clear ice. At Icy cape there is a bold headland of this nature from which bergs are continually falling with a thunderous roar that may be heard fully twenty miles away. On the crest of the cliffs of clear blue ice there is a dark band formed by the edge of the sheet of debris covering the glacier, and showing that the moraine which blackens its surface along its outer margin is entirely superficial. At Sitkagi bluffs the glacier is again washed by the sea but the base of the ice is there just above the water-level and recession is slow. The bluffs are heavily covered with stones and dirt, and icebergs do not form.

At the heads of the gorges in the margin of the glacier leading to the mouths of tunnels, the dirt-covered ice forms bold cliffs which are most precipitous at the heads of the reëntrant angles. The eastern margin of the ice sheet, facing Yakutat bay, is low and covered to a large extent with water-worn debris. The ridges on the glacier formed by moraines are there at right angles to the margin of the ice and are bare of vegetation. The reason for the exceptionally low slope of the eastern margin of the ice sheet seems to be that the current in the ice is there eastward and the glacier is melting back without leaving a stagnant border.

Marginal lakes. — The water bodies here referred to are called "marginal lakes" for the reason that they are peculiar to the margins of glaciers. Where rocks border an ice field or project through it they become heated, especially on southern exposures, and, radiating heat to the adjacent ice, cause it to melt. A depression is thus formed along the margin of the ice, which becomes a line of drainage. Water flowing through such a channel accelerates the melting of the ice, at least until a heavy coating of debris has accumulated. When a steep mountain spur projects into an ice field the lines of drainage on each side converge and frequently unite at its extremity, forming a lake, from which the water usually escapes through a tunnel in the ice. Typical instances of lakes of this character occur at Terrace point, at the

south end of the Hitchcock range, and again about the base of the Chaix hills.

When a stream flows along the side of a glacier a movement in the ice or the sliding of stone and dirt from its surface sometimes obstructs the drainage and causes the formation of another variety of marginal lakes. In such instances the imprisoned waters usually rise until they can find an outlet across the barrier and then cut a channel through it.

A glacier in flowing past the base of a mountain frequently obstructs the drainage of lateral valleys and causes lakes to form. These usually find outlets, as in the case of lakes at the end of mountain spurs, through a subglacial or englacial tunnel, and are filled or emptied according as the tunnel through which the waters escape affords free drainage or is obstructed. Several examples of this variety of marginal lakes occur on the west and north sides of the Chaix hills. They correspond in the mode of their formation with the well-known Merjelen See of Switzerland.

Other variations in the manner in which glaciers obstruct drainage might be enumerated, but those mentioned cover all of the examples thus far observed about Malaspina glacier. The conditions which lead to the formation of the marginal lakes are unstable, and the records which the lakes leave in the form of terraces, deltas, etc., are consequently irregular. When streams empty into one of these lakes, deltas and horizontally stratified lake beds are formed, as in ordinary water bodies, but as the lakes are subject to many fluctuations, the elevations at which the records are made are continually changing, and in instances like those about Malaspina glacier, where the retaining ice body is constantly diminishing, may occupy a wide vertical interval.

Drainage begins on the southeast side of Chaix hills at Moore's Nunatak, where during the time of our visit there were two small lakes, walled in on nearly all sides by the moraine covered ice of Malaspina glacier. The water filling these basins comes principally from the high ice fall at the north, where the glacier descends over a projecting spur running east from

Moore's Nunatak. The water escaped from the first lake across a confused mass of debris which had slid from the ice bluff bordering the stream and formed a temporary dam. Below the dam the water soon disappeared beneath deeply crevassed and heavily moraine-covered ice and came to light once more at the mouth of a tunnel about a mile to the southwest. The second lake, at the time of our visit, had almost disappeared, but its former extent was plainly marked by a barren sand flat many acres in extent, and by terraces along its western border. The lake occupied a small embayment in the hills, the outlet of which had been closed by the ice flowing past it. Below the second lake the stream flows along the base of densely wooded knolls and has a steep moraine-covered bluff of ice for its left bank. About a mile below it turns a sharp projection of rocks and cuts deeply into its left bank, which stands as an overhanging bluff of dirty ice over 100 feet high. The stream then flows nearly due west for some 3 miles to Crater lake. On its right bank is a terrace about 150 feet high which skirts the base of the Chaix hills and marks the position of the stream at a former stage. The terrace is about 100 yards broad, and above it are two other terraces on the mountain slope, one at an elevation of 50 feet and the other at 75 feet above the broad terrace. The upper terraces were only observed at one locality, and were probably due to deposits formed in a marginal lake at the end of a mountain spur.

The terraces left by streams flowing between a moraine-covered glacier and a precipitous mountain slope are peculiar and readily distinguishable from other similar topographic features. The channels become filled principally with debris which slides down the bank of ice. This material is angular and unassorted, but when it is brought within the reach of flowing waters soon becomes rounded and worn. On the margin of the channel, adjacent to the glacier, there is usually a heavy deposit of unassorted debris which rests partly upon the ice and forms the actual border of the stream. When the glacier is lowered by melting, the steam abandons its former channel and repeats

the process of terrace building at a lower level. The material forming the terrace at the base of Chaix hills is largely composed of blue clay filled with both angular and rounded stones and bowlders, but its elevated border is almost entirely of angular debris. The drainage from the mountain slope above the terrace is obstructed by the elevated border referred to, and swamps and lagoons have formed back of it. In the material forming the terraces there are many tree trunks, and growing upon its surface there is a forest of large spruce trees.

At the extreme southern end of the Chaix hills the drainage from the northeast, which we have been tracing, joins another stream from the northwest and forms Lake Castani. This lake, like the one at Terrace point, is at the south end of a precipitous mountain ridge projecting into the glacier and drains through a tunnel in the ice. The stream flowing from it is known as the Yahtse and flows for six or eight miles beneath the ice before emerging at its southern margin. Large quantities of both coarse and fine material are being carried into Lake Castani by tributary streams and is there deposited as deltas and lake beds. When the lake is drained, as sometimes happens, vast quantities of this material must be carried into the tunnel through which the waters escape.

On the west side of Chaix hills are several other marginal lakes of the same general character as those just described. The one next northwest of Lake Castani occupies a long narrow valley between two outstanding mountain ridges, and is retained by the glacier which blocks the end of the recess thus formed. This lake was clear of ice July, 1891, and of a dark blue color, showing that it received little drainage from the glacier. Other lakes on the northwest side of the Chaix hills are of a similar nature, and during my visit were heavily blocked with floating ice. On the north side of Chaix hills there are other small water bodies occupying embayments and retained by the glacier which flows past their entrances. The water from all these lakes escapes through tunnels.

The lakes to which attention has been directed are especially

interesting, as they illustrate one phase of deposition depending upon glaciation, and suggest that a great ice sheet like that which formerly covered New England very likely gave origin to marginal lakes, the records of which should be found on steep mountain slopes.

Drainage.—The drainage of the Malaspina glacier is essentially englacial or subglacial. There is no surface drainage excepting in a few localities, principally on its northern border, where there is a slight surface slope, but even in such places the streams are short and soon plunge into a crevasse or a moulin and join the drainage beneath.

On the lower portions of the Alpine glaciers, tributary to the main ice-sheet, there are sometimes small streams coursing along in ice channels, but these are short lived. On the borders of the tributary glaciers there are frequently important streams flowing between the ice and the adjacent mountain slope, but when these come down to the Malaspina glacier they flow into tunnels and are lost to view.

Along the southern margin of the glacier, between the Yahtse and Point Manby, there are hundreds of streams which pour out of the escarpment formed by the border of the glacier, or rise like great fountains from the gravel and bowlders accumulated at its base. All of these are brown and heavy with sediment and overloaded with bowlders and stones. The largest and most remarkable of these springs is the one indicated on the accompanying map as Fountain stream. This comes to the surface through a rudely circular opening, nearly 100 feet in diameter, surrounded in part by ice. Owing to the pressure to which the waters are subjected they boil up violently, and are thrown into the air to the height of 12 to 15 feet, and send jets of spray several feet higher. The waters are brown with sediment, and rush seaward with great rapidity, forming a roaring stream, fully 200 feet broad, which soon divides into many branches, and is spreading a sheet of gravel and sand right and left into the adjacent forest. Where Fountain stream rises, the face of the glacier is steep and covered with huge bowlders, many of which are too

large for the waters to move. The finer material has been washed away, however, and a slight recession in the face of the ice bluff has resulted. The largest stream draining the glacier is the Yahtse. This river, as already stated, rises in two principal branches at the base of the Chaix hills, and flowing through a tunnel some six or eight miles long, emerges at the border of the glacier as a swift brown flood fully one hundred feet across and fifteen or twenty feet deep. The stream, after its subglacial course, spreads out into many branches, and is building up an alluvial fan which has invaded and buried several hundred acres of forest.

In traversing the coast from the Yahtse to Yakutat bay, we crossed a large number of streams which drain the ice fields of the north, some of which were large enough to be classed as rivers. When the streams on flowing away from the glacier are large they divide into many branches, as do the Yahtse and Fountain, and enter the sea by several mouths. When the streams are small, however, they usually unite to form large rivers before entering the ocean. The Yahtse and Fountain, as we have seen, are examples of the first, while Manby and Yahna streams are examples of the second class. Manby stream rises in hundreds of small springs along the margin of the glacier which flow across a desolate torrent-swept area and unite just before reaching the ocean into one broad, swift flood of muddy water much too deep for one to wade.

On the border of the glacier facing Yakutat Bay, however, the drainage is different. The flow of the ice is there eastward, although the margin is probably stagnant, and instead of forming a bold, continuous escarpment, ends irregularly and with a low frontal slope. The principal streams on the eastern margin in 1891 were the Osar, Kame and Kwik. Each of these issues from a tunnel and flows for some distance between walls of ice. Of the three streams mentioned the most interesting is the Kame, which issues as a swift brown flood partially choked with broken ice, from the mouth of a tunnel and flows for half a mile in an open cut between precipitous walls of dirty ice 80 to 100

feet high. This is the longest open drainage channel that I have yet seen in the ice. It is about 50 feet broad where the stream rushes from the glacier, but soon widens to several times this breadth. Its bottom is covered with rounded gravel and sand, and along its sides are sand-flats and terraces of gravel resting upon ice. The swift, muddy current was dotted with small bergs stranded here and there in the center of the stream, showing that the water was shallow. Evidently the stream has a long subglacial course and carries with it large quantities of stones which are rounded as in ordinary rivers. Gravel and sand are being rapidly deposited in the ice channel through which it flows after emerging from its tunnel. Broad sand-flats are being spread out in the lakes and swamps two or three miles to the east. The stream is some four or five miles in length and near Yakutat bay meanders over a barren area perhaps a mile broad. I have called it Kame stream because of a ridge of gravel running parallel with it which was deposited during a former stage when the waters flowed about 100 feet higher than now and deposited a long ridge of gravel on the ice which has all the characteristics of the kames in New England. In the more definite classification of glacial sediments now adopted, this would more properly be called an osar.

Near the shore of Yakutat bay the streams from the glacier spread out in lagoons and sand-flats, where much of the finer portion of the material they carry is deposited. Sometimes this debris is spread out above the ice, and forms level terraces of fine sand and mud which become prominent as the glacier wastes away.

Osars.—The drainage of the glacier has not been investigated as fully as its importance demands, but the observations already made seem to warrant certain conclusions in reference to deposits made within the glacier by subglacial or englacial streams.

When the streams from the north reach the glacier they invariably flow into tunnels and disappear from view. The

entrances to the tunnels are frequently high arches, and the streams flowing into them carry along great quantities of gravel and sand. About the southern and eastern borders of the glacier, where the streams emerge, the arches of the tunnels are low, owing principally to the accumulation of debris which obstructs their discharge. In some instances, as at the head of Fountain stream, the accumulation of debris is so great that the water rises through a vertical shaft in order to reach the surface, and rushes upward under great pressure. The streams flowing from the glacier bring out large quantities of well rounded sand and gravel, much of which is immediately deposited in alluvial cones. This much of the work of subglacial streams is open to view and enables one to infer what takes place within the tunnels and to analyze to some extent the processes of subglacial deposition.

The streams issuing from the ice are overloaded, and, besides, on emerging, frequently receive large quantities of coarse debris from the adjacent moraine-covered ice cliffs. The streams at once deposit the coarser portion of their loads, thus building up their channels and obstructing the outlets of the tunnels. The blocking of the tunnels must cause the subglacial streams to lose force and deposit sand and gravel on the bottom of their channels ; this causes the water to flow at higher levels, and coming in contact with the roofs of the tunnels, enlarges them upwards ; this in turn gives room for additional deposits within the ice as the alluvial cones at the extremities of the tunnels grow in height. In this way narrow ridges of gravel and sand, having perhaps some stratification due to periodic variations in the volume of the streams, may be formed within the ice. When the glacier melts, the gravel ridges contained within it will be exposed at the surface, and as the supporting walls melt away, the gravel at the top of the ridge will tend to slide down so as to give the deposit a pseudo-anticlinal structure. Ridges of gravel deposited in tunnels beneath the moraine-covered portion of the Malaspina glacier, would have bowlders dropped upon them as the ice melts, but where the glacier is free

from surface debris there would be no angular material left upon the ridges when the ice finally disappeared. Such a system of deposition as is sketched above would result in the formation of narrow, winding ridges of cross-bedded sand and gravel, corresponding, seemingly, in every way to the osars of many glaciated regions. The process of subglacial deposition pertains especially to stagnant ice sheets of the Malaspina type, which are wasting away. In an advancing glacier it is evident that the conditions would be different, and subglacial erosion might take place instead of subglacial deposition.

Alluvial cones.—Below the outlets of the tunnels through which Malaspina glacier is drained, there are immense deposits of bowlders, gravel, sand, and mud which have the form of segments of low cones. These deposits are of the nature of the "alluvial cones," or "alluvial fans" so common at the bases of mountains in arid regions, and are also related to the "cones of dejection," deposited by torrents, and to the subaërial portion of the deltas of swift streams. As deposits of this nature have not been satisfactorily classified, I shall for the present call them "alluvial cones."

As stated in speaking of osars, the streams issuing from tunnels in Malaspina glacier at once begin to deposit. The larger bowlders and stones are first dropped, while gravel, sand and silt are carried farther and deposited in the order of their coarseness. The deposits originating in this way have a conical form, the apex of each cone being at the mouth of a tunnel. As the apexes of the cones are raised by the deposition of coarse material, their peripheries expand in all directions, and as the region is densely forest covered, great quantities of trees become buried beneath them. As the ice at the head of an alluvial cone recedes, the alluvial deposit follows it by deposition on the upstream side. The growth of the alluvial cones will continue so long as the glacier continues to retreat, or until the streams which flow over them have their subglacial courses changed. The material of the alluvial cones is as heterogeneous as the material forming the moraines on the border of the glacier, about which

they form, but the greater and practically the entire accumulation is more or less rounded and waterworn. Cross stratification characterizes the deposits throughout, and on the surface of many of the cones, and probably in their interior, also, there are large quantities of broken tree trunks and branches. The coarse deposits first laid down on a growing alluvial cone are buried beneath later deposits of finer material in such a way that a somewhat regular stratification may result. A deep section of one of these deposits should show a gradual change from fine material at the top to coarse stones and subangular bowlders at the bottom. Their outer borders are of fine sand and mud, and when the distance of the ocean is sufficient, the streams flowing from them deposit large quantities of silt on their flood plains. The very finest of the glacial mud is delivered to the ocean and discolors its water for many miles from land.

The formation of alluvial cones about the border of a stagnant ice sheet, and the deposition of ridges of gravel within it, have an intimate connection and are in fact but phases of a single process. The growth of an alluvial cone tends to obstruct the mouth of the tunnel through which its feeding stream discharges; this causes the stream to deposit within the tunnel; this, again, raises the stream and allows it to build its alluvial cone still higher. In the case of Malaspina glacier where this process has been observed, the ice sheet is stagnant, at least on its border, and is retreating. The ground on which it rests is low, but is thought to be slightly higher on the southern margin of the glacier than under its central portion. The best development of alluvial cones and osars would be expected in a stagnant ice sheet resting on a gently inclined surface, with high lands on the upper border from which abundant debris could be derived. These ideal conditions are nearly reached in the example described.

Glacial and ocean records.—Much has been written concerning the character of the deposits made by glaciers when they meet the ocean, but so far as can be judged from the conditions observed about the borders of Malaspina ice sheet, the sea

is much more powerful than the ice. Where the two unite their action, the sea leaves the more conspicuous records. The waters are active and aggressive, while the glacier is passive. Where the glacier enters the ocean its records are at once modified and to a great extent obliterated. The presence of large bowlders in marine sediments, or in gravels and sands along the coast is about all the evidence of glacial action that can be expected under the conditions referred to. Where the swift streams from the Malaspina glacier enter the ocean the supremacy of the waves, tides, and currents is even more marked. The streams are immediately turned aside by the accumulation of sand bars across their mouths, and nothing of the nature of stream-worn channels beneath the level of the ocean can exist. All of the deposits along the immediate shore between the Yahtse and Yakutat bay have the characteristic topographic features resulting from the action of waves and currents and do not even suggest the proximity of a great glacier.

Recent advance.—On the eastern margin of Malaspina glacier, about four miles north of Point Manby, there is a locality where the ice has recently advanced into the dense forest and cut scores of great spruce trees short off and piled them in confused heaps. After this advance the ice retreated, leaving the surface strewn with irregular heaps of bowlders and stones and inclosing many basins which, at the time of our visit, were full to the brim. The glacier during its advance plowed up a ridge of blue clay in front of it, thus revealing in a very satisfactory manner the character of the strata on which it rests. The clay is thickly charged with sea-shells of living species, proving that the glacier, during its former great advance, probably extended to the ocean, and that a rise of the land has subsequently occurred. This is in harmony with many other observations which show that the coast adjacent to Malaspina glacier is now rising. The blue color of the subglacial strata is in marked contrast with the browns and yellows of the moraines left on its surface by the retreating ice, which, in common with the fringing moraines still resting on the glacier, show considerable weather-

ing. Among the shells collected in the subglacial clay Dr. W. H. Dall has identified the following;

Cardium gronlandicum, Gronl.
Cardium islandicum, L.
Kennerlia grandis, Dall.
Leda fossa, Baird.
Macoma sabulosa, Spengler.

Similar shells, all of living species, were previously found at an elevation of five thousand feet on the crest of a fault scarp at Pinnacle pass, showing that recent elevations of land much greater than the one recorded in the marine clay just noticed have taken place. In fact there are several indications that the coast in the vicinity has been rising and that the same process is still continuing.

ISRAEL C. RUSSELL.

THE OSAR GRAVELS OF THE COAST OF MAINE.[1]

In the interior of Maine we find the long osars interrupted near the tops of transverse hills crossed by the glacial rivers, and still more interrupted on steep southern slopes. In such situations it is evident that the velocities of the osar rivers would be greater than the average, with the result that the rivers swept their channels clear of sediments. The conditions were those of transportation by the glacial rivers rather than deposition.

If we follow the osars southward toward the ocean we find at about the average distance of thirty miles from the shore that the osars begin to be interrupted in a different manner from that in the interior. Gaps begin to appear in the ridges in level ground where the land slopes could not cause an accelerated motion of the glacial rivers. Indeed, the gravels more often appear on the tops of low hills than in the lower grounds. Going southward the sizes of the ridges become on the average smaller, their materials rather coarser, the intervals longer, and finally near the northern ends of the bays or fjords of the coast they disappear. If they continue farther southward or into the sea, it is in masses that are so small as to be covered out of sight by the marine beds. The coastal towns are usually covered by clays, and road gravel is often in great demand. The vigilance of town officers has often detected beneath the marine clays small mounds of gravel that form the southern ends of gravel systems. To the south we reach a region where no gravels have been found. When wc find an osar system graduating into mounds so small that not even the selectmen of a Maine town can find water-washed road gravel, we may be sure that our osar has come practically to an end. I have examined the charts of the Coast

[1] Condensation of chapters of a report on the Glacial Gravels of Maine, written for the U. S. Geological Survey.

Survey showing the sea bottom for a few miles off the coast. If there were any broad gravel hills 100 to 150 feet high, such as are found thirty miles north from the bays, they ought to be shown, and I do not find them. The charts often report gravelly bottom but it is uncertain whether this is till or glacial gravel. I find no evidence that these soundings showing gravel are connected with ridges of any considerable size. While then it is as yet impossible to know the geological significance of the gravel reported on the sea floor, yet in most cases the gravels end so evidently north of the shore that the interpretation is distinctly favored that none of the gravel systems reach far beneath the sea. No osar gravels have I been able to find on the islands situated south of the apparent ends of the gravel systems.

There are other significant peculiarities of the coastal gravels than those to be named in this paper, and many collateral or alternative questions and hypotheses had to be worked out. For the present we confine our attention to the three following characteristics :

1. The decrease in the average size of the glacial gravel masses as we go toward the coast till they often become cones not more than twenty or thirty feet in diameter and four or five feet high. In general, the marine clays are twenty feet or more in depth and would easily cover out of sight masses smaller than those above named.

2. The increasing discontinuity of the osar systems, the gaps between the successive ridges, massive mounds or plains, lenticular hills, domes, cones, and mounds increasing from a few rods up to two or three miles.

3. The practical ending of the osar gravels near the north ends of the fjords (fjord line). It is not meant to assert that there are absolutely no osar mounds beneath the sea or on the land south of the discovered gravels. But if any exist they are hidden by the marine beds, and are so insignificant in size as compared to the osar gravels found a few miles farther north that for all practical purposes we may assume that they end. If the osar mounds go on decreasing as fast southward as they do

within the last few miles of their traceable courses, they certainly must entirely disappear within three to five miles of their apparent endings. We omit here the overwash gravels that were deposited in front of the ice beneath the present ocean.

It is to be noted that these gravels are in lines or systems, and often toward the north pass into continuous osars. They are regarded as having been deposited by a single glacial river, that is, all that are classed as a single system. The intervals between the separated gravel masses are not due to erosion of a once continuous body. But the problem relates to the reasons why a single glacial river deposited sediments at intervals here and there within its channel.

In placing the problem before us, we have to consider the extent of the region in question. The above-named characteristics are associated with each other along two hundred miles of coast. Every few miles throughout this district we come to places where a glacial river has left its sediments. All these gravel systems exhibit the first two of the above named characteristics, and all but four or five, the last. Three osars end at the shore but near the north end of Penobscot bay several miles north of the general fjord line. Two others, perhaps the largest systems in the state, come down to the shore and the soundings seem to support the conclusion that they extend for a short distance under the sea. Horizontally, these changes mostly take place within a belt not far from thirty miles in breadth; vertically in most cases between sea level and the two hundred feet contour. The last named, the ending of the gravels, occurs between contours hardly fifty feet apart.

It is granted that the sea in late glacial time stood along the outer coast line, a little more than two hundred feet above its present level. In the interior its elevation was more than twice this height. All the beaches along the outer coast, whose height I have measured, have nearly the same elevation. In other words, the surface of the sea in late glacial time was substantially parallel to its present surface in the direction of the coast, though at a higher level.

In the coastal region we find numerous marine glacial deltas deposited in front of the ice by glacial rivers that flowed into the sea, but we do not find such frontal or overwash sediments as naturally form in front of glaciers terminating above sea level. These and other facts prove that the ice had not all melted over the coastal region before the advance of the sea. The subsidence of the land (apparent advance of the sea) either preceded the retreat of the ice over the coastal region or accompanied it in such a manner that all the land free from ice was covered by the sea as fast as the ice melted, up to the time when the sea had advanced northward to the highest beach. That is, up to this time, all the subglacial streams poured into the sea at the ice front and not on land above the sea. It follows that the causes of the ending of the osar systems north of the shore not only acted parallel to the present and former surface of the sea, but also in a region where the basal ice was bathed in sea water.

The presence of deep glacial pot-holes in considerable numbers near the coast proves the existence of subglacial streams in that region. Since there are no glacial gravels near these pot-holes, we have proof that there were rapid subglacial streams that left no gravels. Evidently their velocities were such that they transported all their sediments beyond our field (out into the region now under the sea). For years my conclusion has been that the osar rivers of the coastal region of Maine were all subglacial. Assuming the subglacial streams, the problem now resolves itself into this: How happened it that as the subglacial rivers approached the coast, they all found themselves able to sweep their channels free from sediments at nearly the same elevation?

Without here pausing to consider the genesis of the subglacial tunnels, we confine ourselves to the question, how are the tunnels enlarged? Two physical agencies do most of the work. First, mechanical erosion; second, melting of the ice walls by surface waters. In the case of ordinary mountain glaciers there is usually considerable land on the mountains that is bare of ice, and thus water warmed on the land passes beneath the ice and

helps to enlarge the subglacial or englacial channels. But, in the case of ice sheets covering all the land, the only heat available for enlarging the tunnels (omitting the small amount of basal heat) is the heat absorbed by surface waters and carried by them beneath the ice. It is known that the waters of surface melting often collect in superficial brooks and torrents of considerable size. The absorption of radiant energy from the sunlight is instantaneous, or at least much more rapid than the conduction of this energy as molecular heat from the water to the ice with which it is in contact. Under sunlight all surface waters become warmed a little above 32°, and, as they plunge beneath the ice, they give up their surplus heat to help melt the walls of the subglacial channels. This, I infer, is the most efficient of all the agencies that help to enlarge the subglacial tunnels. Enlargement of the subglacial tunnels is not uniform. Thus, where a surface stream pours beneath the ice and brings a fresh supply of heat into the tunnel, there would be more rapid enlargement than elsewhere. For various reasons, not necessary to be discussed here, the enlargement of the tunnels proceeds unequally.

Given a tunnel gradually enlarging till sedimentation begins, this sedimentation will commence at the most favorable places, as at the local enlargements, or at an obstruction. If, now, the size of the tunnel, or rather the ratio between the tunnel capacity and amount of water increase, sedimentation will take place at more frequent intervals, and if the tunnel becomes large and rather uniform in size, the sediments will form a continuous ridge.

Various causes can be adduced why a glacial stream should deposit a diminishing quantity of sediment, but the controlling cause and almost the only one admissible under the peculiar local circumstances is the following: We grant that as we go southward toward the distal extremity of the glacier the supply of drainage water will increase, as in all drainage systems. But all these surface waters take with them heat as they pass beneath the ice to help enlarge the tunnels. Thus, as it were, each

region of the glacier furnishes the heat to enlarge the tunnels within its own limits. This is the natural career of ordinary ice sheets above the sea.

An important law of the enlargement of subglacial tunnels depends on the velocity of ice movement. Subterranean waters, as those of the limestone caves, go on enlarging their channels from age to age, because they act continuously on the same body of rock. But the subglacial tunnel cannot become thus enlarged, because of the constant renewal of the ice. Other things being equal, the enlargement of the subglacial tunnels is directly proportional to the time during which it is being enlarged, and inversely as the rate of ice flow. Obviously, when the flow is rapid the tunnel never becomes very much enlarged, for before this can happen the ice at any given part of the channel is pushed on to the distal extremity and disappears by melting or by berg discharge.

The details, here omitted, prove there was probably a small acceleration of the rate of ice flow as the coast of Maine was approached, hence the rate of enlargement of the ice channels would not increase so rapidly as the supply of water of local melting. But the surface of that region is much diversified with hills and valleys. The rate of ice flow would be most rapid in the deeper north and south valleys, and would be retarded in the lee of the higher transverse hills, of which there are several long systems. If differences in the rate of ice flow were the only cause of different rates of ice channel enlargement, then we ought, on such an uneven coast, to find evidence of the fact in the distribution of the gravels. Examination shows that this was a real cause of varying rates of enlargement, but it was a minor cause. This cause alone could not have enabled all the subglacial rivers to clear their tunnels of sediments at the same or nearly the same horizontal line. It would have acted at various levels, according to the conditions for rapid ice supply from the north.

We have seen that the ice in late glacial time flowed into the sea in the coastal region of Maine. It remains for us to inquire

what is the effect of the flowing of a glacier down into a body of water upon the enlargement of the subglacial tunnels. In such a case the tunnels and all crevasses opening into them are permanently filled with water up to the level of the surface of this body of water. But it is by the crevasses that the waters of local melting get down into the subglacial tunnel. The permanent water in the crevasses is at the temperature of 32°. As the waters of surface melting in the region whose basal ice is submerged in the sea or other body of water pour into the crevasses they cannot at once fall to the ground and enter the tunnels, but they fall into the water in the crevasses that already fills them to the level of the permanent body of water. The large streams find their way pretty directly into the tunnels, but all the smaller streams and trickles become so mixed with the cold waters in the crevasses that their heat, instead of being consumed in enlarging the tunnels, is largely expended in melting the ice walls of the crevasses above the level of the tops of the roofs of the tunnels.

Thus the flowing of a glacier down into the sea interferes with the natural transfer of heat beneath the ice whereby the tunnels are enlarged in large part. But the supply of surface waters is the same over the area whose base is submerged as elsewhere. The conclusion follows, that as we go toward the distal extremity of a glacier that flows into a body of water, the supply of drainage waters would be increased more rapidly than the tunnel capacity. This would result in increased velocity of the rivers, with a corresponding increase in power of transportation. In other words, they would do just as the osar rivers of Maine did as they approached the coast—would deposit sediments at longer and longer intervals, and in smaller quantities, and finally would sweep their tunnels free from all sediments.

Now it is certain and inevitable that the submergence of the basal ice should restrict the enlargement of the subglacial tunnels, yet it is an open question whether this was sufficient to account for the peculiar development of the coastal gravels.

We have seen that these changes take place within a belt not

far from thirty miles wide. Without assuming any definite rate or rates of ice movement we can at least all agree that it would take many years for the ice to advance such a distance. An obstruction to the natural transfer of heat beneath the ice, and consequent enlargement of the tunnels, though it might be slow in its action, would, after a term of years, have a cumulative effect on the development of the tunnels, at least in cases where the subglacial rivers flowed in channels parallel with the ice flow.

We have seen that the three features of the coastal gravels above stated are associated together over a wide area, and would appear to have a common origin. Glacial rivers of different lengths, from five up to more than one hundred miles, all show the same development. At almost the same elevation they all were able to sweep their tunnels clear of sediments. We must seek for some cause capable of acting along two hundred miles of coast in lines approximately parallel to the surface of the sea. What but the sea itself could do this under so many varying topographical and glacial conditions?

Rightly interpreted, it would appear that the termination of the gravel systems north of the shore line is itself a proof of the former elevation of the sea. We may leave it as an open question how far the sea acted in other ways—such as by diminishing the effective "head" of the subglacial streams, etc., but that the sea was chiefly responsible for the peculiar development of the coastal gravels, I am persuaded, is the best interpretation of the facts. And of all the ways in which the sea or other body of water that submerges the base of a glacier affects the subglacial streams and their tunnels, I have been able to discover none so potent as that which is above described, whereby the enlargement of the tunnels is obstructed.

Where subglacial rivers flowed up and over transverse hills, as they often did in Maine, there would be a body of slack water in the tunnels, like a sewer trap, on the north sides of the hills. Some of these bodies of slack water or dams on the north sides of hills were from five to ten or fifteen miles long, and in one

extreme case about twenty miles. The ice would be so long passing over such distances that we could expect that the basal water would restrict the enlargement of the tunnels sufficiently to show a characteristic development of the gravels, such as narrowness of the osars or gaps without gravels. While in such situations I nowhere find so extreme a development as in the coastal region, yet there are numerous facts that are best interpreted by the hypothesis that the basal waters of the slack water dams in the subglacial tunnels did somewhat obstruct the enlargement of the tunnels; and thus far I have found none inconsistent with that hypothesis.

The critical reader will have noted that the belt of transition of the coastal gravels of Maine is approximately parallel to the ice front at one stage of the retreat of the ice. It is also somewhat parallel to the southern margin of the *névé*. It has been necessary to consider whether the coastal gravels were retreatal phenomena, connected with some late stage of the ice sheet's history, also what effect would be produced by the retreat northward of the *névé* line, whether the discontinuous gravels were due to the gradual rise of the sea, etc. The result has been to relegate all the suggested agencies to a subordinate position with respect to the two causes above named—a probable small acceleration of ice flow near the coast and the limited enlargement of the subglacial tunnels over the area whose basal ice was submerged in the sea.

GEORGE H. STONE.

THE HORIZON OF DRUMLIN, OSAR AND KAME FORMATION.

IN an article in the first number of this journal on the nature of the englacial drift of the Mississippi basin, I endeavored to show by evidence drawn from a wide area of the interior that erratics dislodged from the summits of the hills of crystalline rock in the northern region by the Pleistocene ice-sheet were borne south within the ice in such a way as to be kept separate from the basal material throughout the whole course of their transportation, and that they were at length let down upon the surface of the basal drift at the margin of the ice as a separate deposit. The evidence seemed to force the view that the basal material was not carried upward by transverse ice currents even into the heart of the glacier much less to its surface. The facts there cited seemed to make it clear that there is not only a theoretical but a practical horizon of demarcation between the englacial drift and the basal drift, and that under circumstances of this kind—and they seem to have wide prevalence—there is little or no confusion of the two. Very possibly this conclusion does not hold equally good in very hilly or mountainous regions.

In carrying out into further application this distinction, it seems well to specify the precise sense in which the term englacial is used. It may be applied to any erratic material that, at any time during its transportation, may be enclosed within the ice even though it be essentially at the bottom of the glacier and may have been actually at the bottom a little before and may again be at the base a little later on; or it may be applied, less technically but more significantly, to that only which is embedded in the heart of the ice and borne passively along with it free from basal influences until it is at length brought out to the surface of the terminal slope by the agency of ablation.

It is clear that all erratic material as it was brought to the front edge of the ice appeared either on the surface or at the base. There is here a sharp physical horizon of demarcation. If the material that had been basal some distance back from the edge was carried up to the surface, or carried up so far into the body of the ice that the surface was brought down to it by ablation near the border, it is evident that it must have become commingled with that which had been englacial or superglacial from the moment it was dislodged from its parent hills, and hence this horizon of demarcation would not distinguish between the two classes of material as such. The distinction would rest upon mode of transportation and deposition. But if the interpretation of the article referred to is correct and holds good generally in similar regions, the horizon becomes a plane of separation between the classes of material as well, and assumes much importance in practical glaciology. It was, however, obviously not an absolute plane of demarcation, even at the border of the ice, and when we attempt to apply it to sections lying farther back, it needs some qualification.

Without doubt material which was picked up by the ice along its base was thrust up into it to greater or less heights. As a particular instance, beds of rock which were inclined upward toward the oncoming ice were obviously disposed to thrust themselves into it as they were being tilted out of their positions. They appear to have rotated upon their lower edges, as upon a hinge, and were probably only removed from their places after they had been turned into a vertical position or perhaps somewhat beyond it. They were then almost wholly embedded in the ice, and so, in a limited sense, they were englacial. So also it is extremely probable that, in the case of undercut ledges, sharp ravines, narrow gorges, and similar very abrupt inequalities in which the surface was suddenly depressed, there was more or less overriding of the basal currents of the ice and consequent incorporation or overplacement of the material held in the bottom of the overrunning portion. But notwithstanding the fact that this material became englacial in a limited sense, because

it was not absolutely at the bottom of the ice, I think, in a genetic view, it is to be regarded as basal unless it was lifted so high into the body of the glacier as to be borne onward thenceforth entirely within the body of the ice and free from basal influences so that it was at length carried out to the surface as it approached the terminal edge, and was deposited as superglacial material. If the material remained approximately at the bottom of the glacier and again descended to the absolute base of the ice, it seems to me best to regard it as basal, even though it may be, for a time, completely enveloped within the ice. This seems best, because it represents the significant factor in the operation. In origin, it was basal, and, in the end, it became basal. It was only englacial by accident, temporarily.

Opposed to the agencies that tended to carry material from the absolute bottom of the ice into its basal portion to limited heights, there were several agencies that tended to bring it back to the absolute bottom. (1) The conduction of internal heat contributed slightly to this by melting away the base of the ice. The annual amount was undoubtedly very small, but the cumulative effects upon the bottom of any particular column of ice during the last five hundred miles of its journey (and this much is involved in certain aspects of the problem) was probably very appreciable and was manifestly greater in proportion to the slowness of the ice movement. (2) Basal friction undoubtedly gave rise to a much larger wastage and so lowered the embedded debris. (3) The introduction of warm waters from the surface, through the agency of crevasses, also caused wastage of the bottom, but this was obviously limited to such portions as were accessible to these waters and the effects were unequally distributed, although the positions of the streams undoubtedly changed from time to time, and this tended to spread the effects more generally over the bottom. (4) It is probable that there was a certain amount of penetration of solar rays through the ice. As the surface of a glacier is usually granular, only a minor portion of the sun's rays probably succeeded in penetrating to the transparent ice below. But such portions as reached this

were competent to traverse very considerable depths of ice without being entirely absorbed, being chiefly waves of short vibration. Those who have been beneath glaciers have observed that the amount of transmitted light is not inconsiderable. The transmitted rays of short vibration, so far as they reached the bottom, were arrested and, by transformation to rays of longer vibration, brought to bear upon the base of the glacier. The basal wastage from this source may be presumed to have increased somewhat in proportion as the ice thinned towards its margin, but this would be offset to some degree by a probable increase of surface detritus that would cut off the rays. The combined effect of these agencies would appear to have been not inconsiderable.

(5) In any vertical section of a glacier the lagging of the basal portion causes the plane of the section to lean forward, which means that each part is brought nearer to the bottom, carrying with it whatever material is enclosed. This being a general phenomenon justifies the conclusion that the tendency of the ice of the interior of a glacier is to flow obliquely forward and downward. Exceptions to this may be found when the resistance of a given portion of the base is greater than that of the portion immediately in its rear, in which case the latter may tend to flow over the former, but this will be reversed when the ratio of resistance is changed and would be, at most, but a variation of action, not a general law of action.

The combined effect of all these agencies was, if I reason correctly, to bring back to the base of the ice any material that owing to the special causes named, or to others, had been forced up into the lower parts of the ice. They tended to preserve the basal character of whatever had once become basal. And this seems to be supported by observations on existing glaciers.

These considerations have a very specific bearing upon the horizon at which drumlins, osars (eskers), and kames were formed. These all contain large quantities of local material, of basal derivation. If the view here stated is correct, these must be very strictly basal deposits, in general. There are doubtless

some qualifications and exceptions. This conclusion is not at all new, for, as is well known, it has been reached by several students of these phenomena quite independently. But an approach to the question along the line of evidence presented by *bowlder belts* and *bowlder trains* has its own advantages. It bears particularly upon a new view of the origin of drumlins recently advanced by one of our most experienced glacialists in which they are held to have been chiefly formed from englacial drift which "had become superglacial by ablation and was afterwards enclosed as a stratum within the ice-sheet, being thence amassed in these hills."[1]

In the midst of the drumlin area of south-central Wisconsin, there arise from beneath the Paleozoic strata a few scattered knobs of quartzite and quartz-porphyry from which erratics have been derived and borne away to varying distances, constituting bowlder trains of the most definite type. These are radically different from the bowlder *belts* discussed in my previous paper. The quartzite outcrops near Waterloo, in Jefferson County, are the most favorably situated for the purposes of the present study, because they are right in the heart of the most pronounced drumlin area and have made large contributions to the erratic content of the drumlins themselves. My associate, Mr. I. M. Buell, has been engaged for some time in a very careful study of the abrasion which these quartzite outcrops suffered from glaciation and of the distribution and special relationships of the erratic material derived from them. The drift movement was here to the south-southwestward and quartzite blocks derived from these outcrops enter in great abundance into the constitution of the drumlins lying in that direction. Several features of their distribution and nature are worthy of special note.

1. The quartzite bowlders are not simply scattered over the surface of the drumlins, but are distributed throughout their entire mass so far as accessible to observation. As the drumlins bear evidence of gradual accretion, it seems necessary to suppose that they were built up by successive additions of material

[1] "Conditions of Accumulation of Drumlins," Warren Upham, *American Geologist*, December, 1892. pp. 339–362.

derived from a stream of drift passing over the quartzite ledges and making constant additions from them.

2. The drumlins are found to be filled with quartzite erratics immediately in the lee of the ledges. There are even drumlins which lie directly upon the ledges and envelop them in large part, which are found free from local quartzite derivatives on their stoss ends, but are inset with them in their lee ends. The quartzite content of the leeward portion ranges, in observed sections, from 5 per cent. to 10 per cent. of the whole drift. In one case, Mr. Buell found an isolated drumlin to contain all of the quartzite of its particular kind observed in the vicinity. It evidently completely envelops the parent ledge and retains the most of its derivatives. Several bowldery mounds, that may be regarded as drumlins in miniature, occur in the immediate lee of the ledges, in which the quartzite drift was estimated to comprise from 20 per cent. to 75 per cent. of the whole. The material, in these instances, appeared to be chiefly former talus of the quartzite outcrops. Setting in thus promptly immediately at the quartzite outcrops, the erratics are found to diminish very markedly in proportion as the distance increases. A mile and a half away from the outcrops, a careful estimate of the quartzite content gave 3 per cent. of the whole mass of the drift. The average for the area between 1 and 6 miles is 1-1½ per cent.; between that and 20 miles 1 per cent.; between that and 45 miles .364 per cent., and in the terminal moraine .0477 per cent. The surface distribution shows a similar diminution. The estimated amount of quartzite on the very bowldery mounds near the ledges was 17,700 cords; at other points within six miles of the outcrops 12,650 cords; at medial points 1,409 cords; on the terminal moraine, about 45 miles distant, 747 cords. This very rapid diminution in the quantity of quartzite erratics is significant in showing that the element of resistance to transportation was an influential factor. This is precisely what is to be anticipated on the hypothesis that these bowlders were pushed or dragged along the base of the ice. It seems very far from what is to be expected, however, on the

hypothesis that the erratics rose in the ice and were transported englacially in any considerable degree. In this case, the greatest accumulation should have been at the terminal moraine where the ice halted longest. It seems to be also difficult to understand, on the hypothesis offered by Mr. Upham, how the drumlins lying immediately on the ledges and immediately in their lee could have been filled so largely with quartzite bowlders. Certainly the bowlders could not have risen in the ice so high as to have become exposed at its surface by ablation and then have been overflowed by a new accession of ice and moulded into the drumlin form, and at length have been let down by the melting of the ice beneath without more forward movement than observation shows. The simplicity of the facts do not seem to tally with the complexity of this theory.

3. The amount of abrasion which the bowlders suffered bears specifically upon the question of the mode of their transportation. The parent outcrops gave rise to erratics of three kinds. (1) In Paleozoic times the ledges stood as islands in the seas, and there accumulated about them very coarse conglomerates of quartzite. From these, a portion of the erratics were derived in an already rounded condition. The character of this rounding and the superficial changes the pebbles underwent before the glacial period made it possible for Mr. Buell to distinguish these with measureable certainty in following the train until abrasion had destroyed their surface characters. (2) Talus blocks accumulated about the bases of outcrops before the ice invasion that formed the drumlins. There was an earlier invasion which bore quartzite erratics westward. The later invasion bore them southwestward. The talus blocks under consideration are, perhaps, in the main, those that were derived from the quartzite knobs in the interval between the two. They are distinguishable from blocks disrupted by the ice by means of the weathered character of their several surfaces, so long as these remain unabraded. (3) The third class of erratics are those that were derived by direct action of the ice upon the parent knobs. These are distinguished by their unweathered fracture surfaces.

Among five hundred bowlders examined by Mr. Buell at two railroad sections, distant less than three miles from the most remote of the parent ledges, only ten were noted that did not plainly show by rounded edges and blunted angles the effects of glacial attrition. At a point less than twelve miles distant, the abrasion had so far obliterated the surface characters that it was hardly possible to determine to which of the three classes above indicated the erratics had originally belonged. Farther on, the evidences of abrasion are still more marked. The degree of abrasion did not appear to be equally great in the case of some of the bowlders found on the crest of some of the high ridges and on the surface of the terminal moraine. Mr. Buell's observations were made with the hypothesis of englacial transportation in mind as an accepted working hypothesis, but with only meagre results in the drumlin area. Studies at two points on the slope of the outer ridge of the terminal moraine and on the edge of the overwash plain gave fifty-six bowlders that were only slightly affected by glacial abrasion and eighty-eight which showed by their rounded forms and scratched surfaces the effects of severe glacial reduction. While therefore the observations do not exclude the hypothesis of a small amount of englacial transportation, if slight abrasion be taken as sufficient evidence of this, they limit it to a quite trivial factor of the whole mass.

The combined testimony of the foregoing facts seems to me quite decisive in its bearing on the proposition that the derivation, transportation and deposit of the quartzite bowlders was almost exclusively subglacial or at least closely basal. As these bowlders enter into the structure of the drumlins from base to summit, and are mingled with much other local material, the foreign element being relatively small, they seem to compel the same conclusion respecting the whole of the material which was built into the drumlin forms.

Mr. Buell has found what he regards as satisfactory evidence that an older train of bowlders was carried directly westward at the time of the earlier drift and that the later ice movement toward the southwest crossed this train obliquely and distributed

it over a much greater area than it originally occupied, forming a secondary train. The erratics of this secondary train, he finds much smaller in general and marked by greater evidence of glacial reduction than those of the unmodified later train. This has a double bearing upon the question of the origin of the drumlins in that it indicates basal transportation in both epochs and in that it indicates a direct accumulation of the drumlins *de novo* during the later incursion. It seems to exclude the view that the drumlins are remnants of the older drift; for, since the older train was westerly, there would be no quartzite material in the old drift lying southwesterly from the outcrops, and hence none would appear within the body of the drift in that region when worn into drumlin forms. But it is just here that quartzite erratics appear in their greatest abundance and permeate the body of the drumlins most impartially. The direct south-southwesterly bowlder train is so predominant that the older, and now more scattered, westerly one was not recognized by the earlier observers.

The testimony of these *bowlder trains* (basal phenomena distributed along the line of drift movement) combined with that of the *border belts* (superficial phenomena distributed transversely to the drift movement and parallel to the edge of the ice) seems therefore to add some special weight to the already familiar evidence supporting the view that drumlins are strictly basal aggregations.

There are no well defined osars (eskers) in this drumlin region, but there are tracts of gravelly knolls and ridges some of which seem to represent longitudinal glacial drainage lines, and so, genetically speaking, to stand for the esker phenomena. Aggregates of the kame type, or of an unclassifiable type of this general order, occur not infrequently among the drumlins. In connection with the moraines bordering the district, kames of the typical variety have an abundant development. Into all these, so far as they lie within the area of quartzite distribution, the quartzitic material enters in even greater abundance than into the average unmodified till of the drumlins themselves or

of the moraine. The mean of several observations upon kame-like accumulations of gravel lying within ten miles of the parent outcrops gave Mr. Buell 5 per cent. of quartzite, in the interior material accessible in sectional exposures. At points about midway between the parent ledges and the terminal moraine, forty-five miles distant, the average amount was found to be 1.2 per cent. Measurements made nearer the limit of the later drift showed .39 per cent., while on the margin, the quantities were usually found too small to be estimated in percentages.

It thus appears that the law of distribution found in the drumlins holds good for the kames save that the relative percentage of quartzite in the latter is greater than in the former; a fact which finds its explanation, in part certainly, in the fact that the clayey and other fine material of the drumlins enters into the estimate of percentage for them while it does not in the case of the kames, it having been chiefly washed away; and perhaps also, in part, in the fact of greater resistance to wear on the part of the quartzite.

These kame-like accumulations sometimes lie in the lee of the drumlins and form a part of the common hill or ridge, their contours blending into the common contours of the drumloid form, so that there can be no doubt that the two portions were simultaneous in formation, and that the horizon and environment of their accumulation were identical. In other instances, they are associated with cols or with valleys among the drumlins in such a way as to leave no doubt that the kames and drumlins were closely associated and essentially contemporaneous in formation. As some of these kame-like forms lie very near the parent quartzite ledges, it seems quite impossible to suppose that the quartzite erratics were borne to the surface by internal cross movement of the ice, and afterwards let down so near to the origin of the material as we find them. There seems, therefore, no escape from the conclusion that these are also very strictly basal phenomena, being but assorted and re-aggregated portions of the common drift of the drumlins and the general ground moraine.

Returning to the region of the superficial bowlder *belts* in Illinois, Indiana, and Ohio, we find hillocks of the kame type distributed throughout the same tracts as the bowlders, indeed, practically lying beneath the bowlder belts themselves. Some of these I described nine years ago in the American Journal of Science in an article entitled "Hillocks of Angular Gravel and Disturbed Stratification."[1] Additional evidence of the same import has been since gathered. Among the materials of these kame-like aggregates, it is not uncommon to find a complete series of gradational forms, ranging from incorporated masses or tongues of typical till of the ground-moraine type, through partially modified masses and layers of half-till, half-gravel, to completely assorted and stratified material, thus showing every stage of the derivation from the common underlying and surrounding till. The attrition of the material shows a like gradation. In some portions the clayey constituents of the till have been simply washed out leaving the rock fragments which show almost no perceptible wear from water. In others, the rounding has been more considerable, and in still others, there has been a reduction to the common rounded gravelly type. Even this is not usually well rounded. The less modified fragments not uncommonly show glacial striation. All these variations occur within the limits of a single hillock, and are often so intimately associated as to compel the conviction that the gravel is but a partially assorted derivative from the till of the region. In some of these hills the stratification is disturbed, not as though the beds had been let down by the removal of ice below, but as though they had been pushed horizontally by glacial pressure. The essentially local derivation of the material is demonstrated by the very notable presence of rock fragments derived from the formations of the neighborhood. More than half the material is not infrequently made up of limestone whose origin must be much nearer at hand than that of the superficial bowlder belt. An analysis representative of the gravel and sand of one of these kames gave as much as 70 per cent. magnesian limestone.

[1] Am. Jour. Sci., vol. XXVII, May 1884. Pages 378-390.

It is probably safe to say that in selected instances at least 90 per cent. of the material was derived from the Paleozoic series and more than half of this from the vicinity. This is, however, too large an estimate for the average, but the local constituents were never seen to be other than pronounced if not predominant. Material of local derivation also enters into the constitution of the sand and clay as well as the coarser material showing that the hillocks are made up not only of the glacially ground rock-fragments, but of the glacial grindings. The whole aspect of the material of these kames is so strikingly in contrast with that of the superficial bowlder belt and points so definitely to their derivation from the common sheet of subglacial till as to seem to put beyond doubt the view that they are quite strictly basal in formation.

Osars of the typical variety have comparatively few representatives in the plain tracts of the interior, but several well characterized instances occur. It is notable that, in most of these instances, as pointed out by Mr. Leverett, who has perhaps carefully studied a larger number of them than anyone else, they often lie in river-like channels cut into the till sheet of the region. There are perhaps a dozen of these that have been studied, varying in length from a few miles to about fifty miles. These channels have the characteristics of river troughs, and usually stand so related to the margin of the ice as to seem to indicate that they were lines of subglacial drainage during the same glacial stage as that in which the osars were formed. These channels are so related to the surface slopes that they could not have been formed by free open-air streams. The restraining aid of ice seems necessary. While no demonstration of the history of their formation can be claimed, the most plausible explanation appears to be that the river-like channels were cut by subglacial streams at a time when the urgency of the ice was such as to compel basal cutting, and that, subsequently, when the pressure of the ice was less insistent, and its motion feebler, the draining stream was permitted to fix its channel in a tunnel cut in the under surface of the ice, which

otherwise occupied the channel previously cut, and that the stream gradually built up its gravels within the tunnel so formed, essentially as indicated by Professor Russell in the case of tunnels under the Malaspina glacier. While the inferences drawn from this peculiar association of the osar ridges with river-like channels cannot be urged with the same force as the preceding considerations, they seem to support them in some degree. The constitution of these osar ridges is of the same local character as that of the kames above discussed except that perhaps it is less narrowly local and less intimately related to the underlying formations. The difference, however, is not marked.

From the foregoing evidences, the inference is drawn that the osars and kames of the plain region of the interior are basal phenomena in a degree almost as complete as the drumlins or the ground moraine. Inferences from such evidences as have been cited cannot, however, be applied with so much rigor in the case of osars and kames as in the case of drumlins, for the subglacial streams, that are held to have formed them, cannot be assumed to have always pursued strictly basal courses. Conditions may be supposed to have arisen which would have forced the streams into channels above the base of the ice, or even up over the ice in the thin marginal portion, so that accumulations may have taken place that were less strictly basal than those of the drumlins, and it is of course possible that kames and osars may have been formed, in particular instances, out of the englacial and superglacial material of the ice; but, following what seems to me the legitimate teachings of the foregoing lines of evidence and of observation, there seems warrant for concluding that such instances, though theoretically possible, are practically rare. I beg that it may be observed that these conclusions are drawn from the phenomena of the plain region of the interior and are applied to it, with the full recognition of the possibility that in hilly and mountainous regions modifications of the conclusions may be necessary.

T. C. CHAMBERLIN.

A CONTACT BETWEEN THE LOWER HURONIAN AND THE UNDERLYING GRANITE IN THE REPUBLIC TROUGH, NEAR REPUBLIC, MICHIGAN.

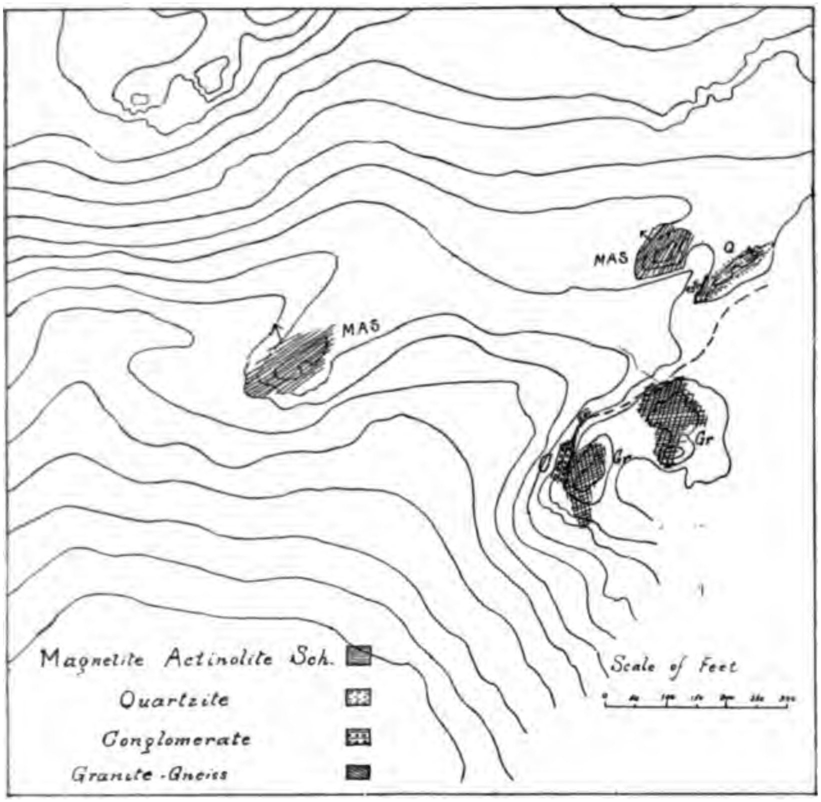
I.

THE lowest member of the Lower Huronian rarely outcrops in the Republic trough. Brooks on his large scale map of Republic Mountain and vicinity, 1869, shows but two exposures of the lower quartzite. They lie south of the mine, in the bend of the horseshoe, and were discovered by Pumpelly and Credner in 1867. Some 250 or 300 feet southwest of the westernmost of these, I have recently found a conglomerate resting upon granite, the contact of the two rocks being very well exposed. It is interesting to note that the locality is very close to that figured by Brooks[1] to show that the strike of the quartzite and of the magnetite-actinolite-schist just above it, runs directly across the foliation in the underlying gneissoid granite. From this he inferred an unconformability between the Huronian and the Laurentian.

II. GENERAL RELATIONS.

The accompanying map will make plain the immediate relations between granite, quartzite, and magnetite-actinolite-schist. The magnetite-actinolite-schists occupy a broad belt in the northern part of the area represented on the large scale map (Fig. V), striking between N, and E. at various angles, and dipping W. of N. from 35°–40°. The alternating layers of silica, actinolite and magnetic, or two or all combined, which compose this rock show both a considerable degree of plication, and also a coarse cross cleavage which strikes between N.45°W. and N. 60° W. or roughly in the direction of the axis of the trough.

[1] Geology of Michigan, Vol. I, part I, p. 126.



N. W. ¼, N. E. ¼, Sec. 18, T. 46 N. R. 29 W., Mich.

The map is from a tracing of a manuscript copy of Brooks' Map, 1 inch = 200 feet, in the possession of the Republic Iron Co. The area represented on the large scale covers a little more than the N. W. ¼ of the N. E. ¼ of Sec. 18, T. 46 N., R. 29 W. The sketch to small scale shows the relation to the trough as a whole. (Fig. V.)

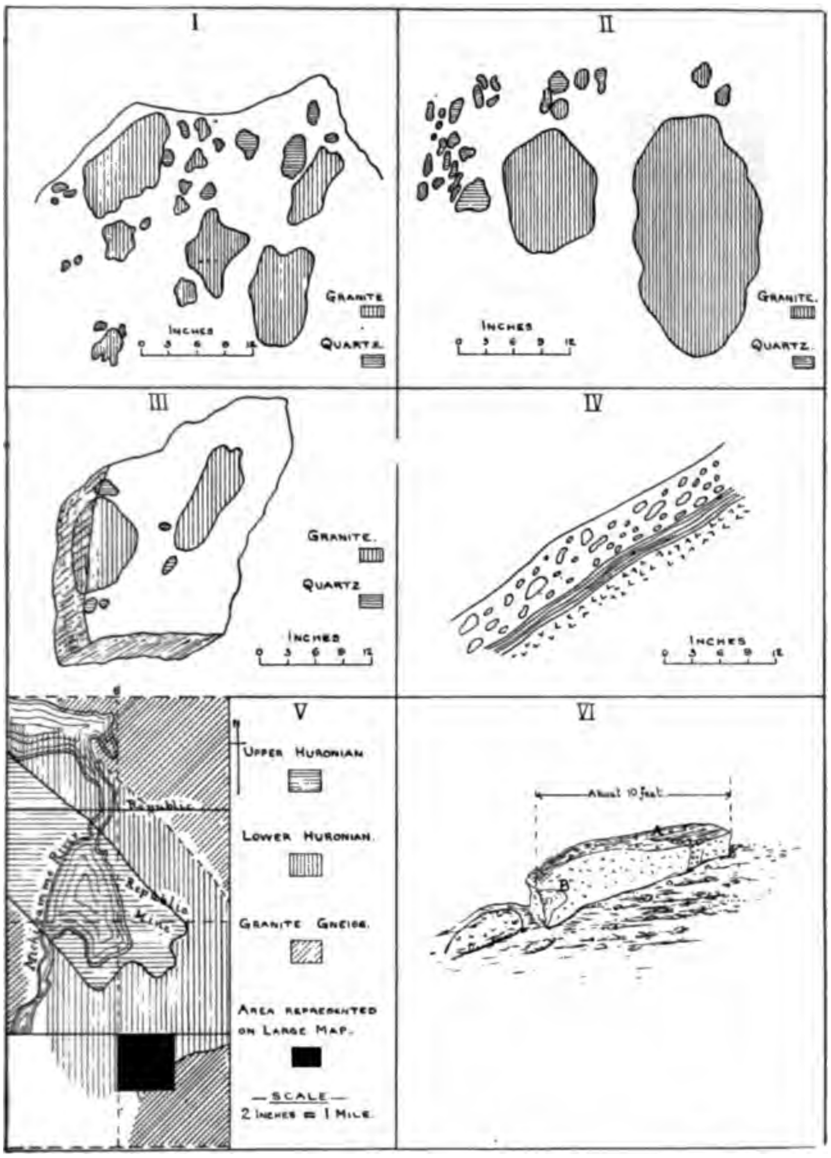
Below the magnetite-actinolite-schists and separated from the nearest exposure by a covered interval of 50 feet is the outcrop of quartzite discovered by Pumpelly and Credner. The outcrop runs about 175 feet along the strike and 30 feet across it. At the N. E. end the strike is about N. 55 °E., and at the S. W. end about N. 20° E., the dip in both cases being to the W. of N.,40°–45°. For the most part the rock is massive and heavily bedded, but the higher portion shows unmistakable sedimentary banding, and even false bedding.

In external appearance and in composition the rock is a very coarse-textured, light-colored quartzite, made up almost entirely of quartz, with some muscovite and chlorite as subordinate constituents. Under the microscope, probably because obliterated by shearing, no original rolled grains were seen, although several slides were examined. Red garnets are occasionally found in the quartzite.

A short distance south and west of the quartzite is a ridge running a little east of north, made up mainly of granite, which presents several bold faces to the west. Near the south end and on the west side, is found upon the granite a westerly dipping fringe of conglomerate, which extends some 50 feet along the strike, as a continuous rock mass. Farther north occasional small patches of conglomerate on the northwesterly sloping granite faces, indicate that the contact follows very closely the direction of the ridge, and lies near its western base.

III. Granite.

The granite exposed on this ridge occurs in both white an reddish weathering varieties, which appear to be, however, iden tical in composition and age. The rock is a coarse mixture c quartz and feldspar of which orthoclase is an important part, an which occurs in Carlsbad twins up to two inches in lengtl Light colored mica and biotite are largely developed in th planes of shearing. The granite contains much pegmatite, bot in veins and in irregular masses. From the contact with tl conglomerate back as far as exposures extend, the granite


I
Granite
Quartz
Inches
0 3 6 9 12
II
Granite.
Quartz.
Inches
0 3 6 9 12
III
Granite.
Quartz
Inches
0 3 6 9 12
IV
Inches
0 3 6 9 12
V
Upper Huronian
Lower Huronian.
Granite Gneiss.
Area represented on Large Map.
— SCALE —
2 Inches = 1 Mile.
Republic
Republic
VI
About 10 feet
A
B

Figs. I.–VI.

traversed by a rude cleavage, which has a general northwesterly direction, and so makes a large angle with the line of contact. The direction of cleavage varies between the limits of N. 40° W. and N. 60° W., and is usually represented by a multitude of planes, in which the micas only are foliated. This cleavage is more strongly developed on the western side of the exposure, near the contact, than elsewhere; and as the cleavage becomes more perfect, the large orthoclase crystals disappear.

IV. Conglomerate.

The matrix of the conglomerate varies between a somewhat micaceous quartzite and a fine grained mica-schist, and shows very distinct bands differing in color, texture, and composition. These bands are thrown into little folds, about northwesterly plunging axes; in strike they conform to the direction of the line of division between the conglomerate and the granite. In this quartzitic matrix are imbedded clearly water-rounded pebbles of quartz, granite, and of a black crystalline schist. The quartz pebbles are as a rule small, few exceeding six inches in diameter. They are of different varieties, clear, milky, brown, and blue gray quartz all being represented. All are more or less thoroughly granulated. They are of very different shapes, and within the planes of bedding, their longer axes lie in different directions. All agree in being smoothly worn and are unmistakably water-rounded.

The granite fragments vary in size from pebbles a fraction of an inch up to bowlders five feet in diameter. The larger are usually thin slabs lying with their flat sides parallel to the bedding. The foliation of the matrix often follows round the inclusions. The contacts between pebbles and matrix are exceedingly sharp; sometimes, however, where several pebbles lie close together, it is a matter of some difficulty to trace the boundary of each on the weathered surface. The distribution of pebbles is very irregular. Near the south end of the exposure they are closely packed, while the northern part of the main exposure has comparatively few. The granite of the pebbles and bowl-

ders appears to be identically the same granite as that on which the conglomerate rests. We find both the white and the red-weathering varieties represented among the pebbles of the conglomerate, and perhaps also the coarse pegmatite. Figures I and II from a sketch made to scale in the field show the appearance of the rock on the dip surface, while Fig. III, drawn to the same scale, shows the outlines of two medium-sized granite bowlders, as seen in cross section on a joint plane.

V. Contact.

At the south end of the main exposure, a nearly vertical cross joint plane on the south of which the rocks have been removed, shows the contact for eight or ten feet across the strike. The relations are represented in Fig. IV.

The conglomerate can be followed by its pebbles with great certainty. The granite below is equally unmistakable. Between the lowest pebble layer of the conglomerate and the undoubted granite, is a zone a few inches wide, that is difficult to assign with certainty to either rock. The contact otherwise is very definite and follows the dip of the conglomerate pebbles. There is no indication that the contact is not simply one of erosion. As the matrix of the conglomerate has been transformed into a crystalline schist as the result of shearing, one may easily suppose that the doubtful zone represents either recomposed granitic detritus or the broken up material of both rocks due to movement along the contact during the folding.

At the north end of the main exposure we have another natural section on a cross vertical plane, shown in Fig. VI. Here a large semi-detached mass of granite, which seems to be joined at the east end to the main mass, lies over a portion of the conglomerate. At its west end it includes a folded fragment of the conglomerate matrix four or five feet long, and two or three feet across, shown at B in the figure.

The junction between the quartz-schist and the granite is sharp, and the banding of the schist is cut at a small angle by the granite. At the east end of the granite mass, at A, a ver-

tical gash four or five inches wide, is filled with conglomerate, connecting with the conglomerate below, and tapering irregularly to a point on the upper surface of the exposure. It is clear, as Professor Van Hise has suggested, that the large mass of granite was a partly detached block of the irregular surface upon which the conglomerate was laid down, and that the sedimentary material at A and B has sifted into cracks existing in it at that time.

VI. SUMMARY.

1. We have near Republic a conglomerate which from its relations must lie at the base of the Lower Huronian, and cannot possibly be Upper Huronian.

2. This conglomerate rests in visible contact upon granite, and is a basal conglomerate;—*i. e.*, it contains numerous waterworn fragments of the granite upon which it rests.

HENRY LLOYD SMYTH.

A PLEISTOCENE MANGANESE DEPOSIT NEAR GOLCONDA, NEVADA.[1]

THE LOCATION OF THE DEPOSIT.

GOLCONDA is a small settlement in northern Nevada, in the valley of the Humboldt river, on the line of the Central Pacific Railroad. A deposit of manganese ore occurs about three miles northeast of the town, on a part of the Havallah Range locally known as the Edna Mountains, and a short distance south of where the Humboldt river has cut its channel through the range. The deposit is small and of no great commercial value, but it is of interest both in the nature of the ore and in its geologic relations.

THE NATURE OF THE ORE.

The ore is a massive, black, glossy oxide of manganese with a hardness varying from 3 to 4. It is generally of a more or less porous structure, often containing cavities lined with mammillary or stalactitic forms, and it sometimes shows apparent signs of bedding. In places it is soft, earthy and pulverulent and contains angular fragments of sandstone, shale and limestone from a small fraction of an inch to several inches in diameter. Sometimes it is stained brown by iron.

The following analysis by R. N. Brackett, Chemist of the Geological Survey of Arkansas, shows the composition of a specimen of this ore dried at 110°-115° Centigrade.

Analysis of Manganese Ore from near Golconda, Nevada.

Manganese protoxide (MnO)	65.66
Oxygen (O)	10.31
Ferric oxide (Fe_2O_3)	3.32

[1] This deposit was examined by the writer while investigating the manganese resources of the United States and Canada for the Geological Survey of Arkansas, and was first described in Vol. I. of the Geological Survey of Arkansas for 1890, J. C. Branner, State Geologist, R. A. F. Penrose, Jr., Assistant Geologist.

Alumina (Al_2O_3)	0.34
Cobalt oxide (CoO)	(not determined)[1]
Lime (CaO)	3.44
Baryta (BaO)	5.65
Magnesia (MgO)	1.26
Potash (K_2O)	0.35
Soda (Na_2O)	none.
Phosphoric acid (P_2O_5)	none.
Tungstic acid (WO_3)	2.78
Silica (SiO_2)	1.70
Water and organic matter	4.16
	98.97

Metallic manganese	50.85
Metallic iron	2.32
Metallic tungsten	2.20

It will be seen by the analysis that the ore is an impure oxide of manganese, being possibly a mixture of the peroxide and sesquioxide, though the impurities obscure its true nature. The most remarkable feature of the ore is the considerable amount of tungstic acid present, comprising 2.78 per cent of the ore and corresponding to 2.20 per cent of metallic tungsten. The form in which the tungsten exists in the ore is uncertain. It is possible that it may exist as a tungstate of manganese or iron, or of both, or perhaps of one of the other bases present. It may either have been deposited from solution with the manganese, or it may have been brought in as detritus from an outside source during the deposition of the ore, in the same way as the fragments of rock were brought into the deposit.

Though from a mineralogical standpoint the ore is impure, yet for commercial purposes the analysis shows a good grade of manganese ore, and the presence of the tungsten would give additional value to the ore in the manufacture of certain kinds of hard steel.

THE NATURE OF THE DEPOSIT.

The ore occurs as a lenticular deposit imbedded in a soft white or buff colored calcareous tufa which contains fragments of sandstone, shale and massive limestone similar to those found

[1] There is more than a trace of cobalt present but the amount was not determined.

in the ore and often in sufficient quantities to form a breccia. This material composes a small knoll on the lower slope of the mountain, and lies on the upturned edges of underlying shale. The association of the manganese and the tufa is shown in Figure 1, while the relation of the deposit as a whole to the Edna Mountains is shown in Figure 2. The first figure represents the small knoll on the left hand side of the second figure.

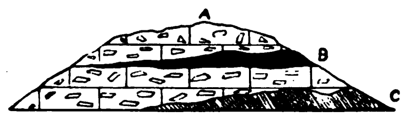


FIGURE 1.—*Section through the Golconda manganese deposit.*

A. Calcareous tufa. B. Manganese ore. C. Shale.

Horizontal scale: 1 inch = 125 feet. Vertical scale: 1 inch = 80 feet.

FIGURE 2.—*Section showing the relation of the Golconda manganese deposit to the rocks of the Edna Mountains.*

A. Quartzite. B. Shale. C. Limestone. D. Manganese-bearing deposit.

Horizontal scale: 1 inch = 500 feet. Vertical scale: 1 inch = 300 feet. (Both of these scales are only approximations.)

The outcrop of the ore-bed appears as a horizontal black band along the side of the knoll facing the mountains, and is very variable in thickness, in some places being represented only as a black line in the white material enclosing it and in others

widening to a maximum, where exposed, of three and a half feet. On the west slope of the knoll the ore bed is not seen at all, the only trace of it being an occasional black stain or dendrites in the limestone along the line where it should outcrop if it extended through to this side. The bed also thins out to the north and south, the whole length of the outcrop being only about 400 feet. East of the outcrop of the ore, the knoll is cut sharply off, as shown in Figure 2, by a rocky area which separates it from the mountains. It will thus be seen that the amount of ore here is limited, and it is probable that the area underlain by it does not cover more than a few acres.

Beneath the ore bed, as seen in one of the small pits that have been made on the deposit, the calcareous material is soft and partakes of the nature of a marl, while above, it is often much harder and has in many places become coarsely crystalline. The crystillization seems to have taken place in spots in the bed, and frequently bodies of crystalline material are surrounded by, and blend into a massive and softer tufa of the same composition.

The fragments of sandstone, shale and gray limestone found in this deposit are of the same nature as the beds of those rocks which comprise the mountain to the east and are undoubtedly derived from them. The pieces of limestone are so markedly different from the calcareous bed enclosing them that they cannot be confounded with it. The rock fragments are of unequal distribution in the deposit, both laterally and vertically, sometimes composing almost half of it, and sometimes being almost entirely absent. They vary from a fraction of an inch to several inches in diameter and are indiscriminately mixed.

The age of the rocks composing the part of the Havallah Range lying east of the manganese deposit is represented as Star Peak Triassic on the map accompanying the Survey of the Fortieth Parallel.[1] As shown in the section given above they are

[1] U. S. Geol. Exploration of the Fortieth Parallel; Clarence King, Geologist in charge; Vol. I., Systematic Geology, map III., Pre-Mesozoic and Mesozoic Exposures. See also report of Arnold Hague, Vol. II., Descriptive Geology, page 680.

composed of sandstones, shales and limestones dipping at steep angles. The upturned edges of the rocks are well exposed from the summit of the mountain to its base, where they are covered by the small knoll or mound containing the manganese deposit.

The crest of the mountain is composed of a quartzite which is of a dark gray color, spotted with brown specks, of a granular structure, very hard and cut by numerous quartz veins. The lower beds of quartzite on the slopes resemble this one in all respects except that they show less trace of their original sandy structure and are more vitreous. The larger part of the slope of the mountain is composed of a more or less slaty shale. It is of a gray or purple color, contains large quantities of thin flakes of mica, has a wavy, undulating structure and in some places grades almost into a micaceous or talcose schist. The lower beds of shale are much thinner than this one, and in some places resemble it in general appearance, while in others they are more calcareous and blend into limestone. The shale which underlies the knoll containing the manganese (see figures) is of a light yellow color on its surface exposure, and is made up of thin friable laminæ. The limestone beds shown in Figure 2 are all of much the same character; they are of a light or dark gray color, sometimes with a reddish tinge, generally massive, though occasionally showing a tendency to a semi-crystalline structure, and are frequently cut by veins of white crystalline calcite.

THE ORIGIN OF THE DEPOSIT.

The Golconda manganese deposit is in the arid region lying between the Rocky Mountains and the Sierra Nevada, and known as the "Great Basin." Parts of this region, as is well-known, were, in Pleistocene, or Quaternary, times covered by several large inland bodies of water, of which lakes Bonneville and Lahontan, described respectively by G. K. Gilbert[1] and I. C. Russell,[2] were the largest. In subsequent times these were

[1] Lake Bonneville, Monograph U. S. Geological Survey, No. I., 1890.

[2] Geological History of Lake Lahontan, A Quaternary Lake of Northwestern Nevada, Monograph U. S. Geological Survey, No. XI., 1885.

mostly dried up, and the only remains of them now are a series of much smaller lakes, occupying hollows in the bottoms of the old lake basins. Great Salt Lake is the modern representative of Lake Bonneville; and Tahoe, Winnemucca, Pyramid and other lakes occupy the basin of Lake Lahontan.

The region about the manganese deposit is on the eastern edge of the area defined by Mr. Russell as the ancient bed of Lake Lahontan, and occupies a position at the head of what was once a small bay protruding about fifteen miles up what is now the valley of the Humboldt River. Mr. Russell,[1] in speaking of the lakes which formerly existed in the Great Basin, says: "Some of these old lakes had outlets to the sea, and were the sources of considerable rivers, others discharged into sister lakes; a considerable number, however, did not rise high enough to find an outlet, but were entirely inclosed, as is the case with the Dead Sea, the Caspian, and many of the lakes of the Far West at the present time." Lake Lahontan did not overflow, and, therefore, the mineral matter brought to it in solution by tributary waters constantly increased in quantity; while the gradual evaporation of the lake steadily concentrated these mineral solutions until they arrived at a state of supersaturation, and were deposited as chemical precipitates. These were, according to Mr. Russell, largely of a calcareous nature, and were laid down as fringes on the margin of the lake at successive stages of evaporation. They are found now at different levels on the old lake border, and mark the ancient shore lines. Mr. Russell has divided them into three classes of "tufas," differing considerably in physical character, and deposited at different levels during the desiccation of the lake. He has named them in the order of their chronological succession, "lithoid," "thinolitic," and "dendritic" tufas. From the analogy of the samples of tufa collected by the writer at the manganese deposit with the description of lithoid tufa given by Mr. Russell, and from the position that the deposit occupies in the old Lake Basin, it is probable that

[1] Geological History of Lake Lahontan, A Quaternary Lake of Northwestern Nevada, Monograph U. S. Geological Survey, No. XI., 1885, page 6.

the calcareous material with which the Golconda manganese deposit is interbedded represents the lithoid tufa of Russell, and that the manganese itself is a local deposit not necessarily characteristic of the variety of tufa with which it is associated. In other words, the deposit represents a lenticular bed of manganese ore interstratified with a calcareous sediment, the latter having been chemically deposited from supersaturated lake waters. It will be seen in Fig. 2 that the manganese deposit occupies a basin in this tufa, that the basin was originally cut off on the east side by the rocks that formed the old shore line, and that it was bounded on its west side by the outer edge of the tufa terrace. Between these limits it extended a short distance up and down the lake shore. This position, as well as the nature of the ore, both tend to show that the bed was originally laid down as a shallow water deposit and subsequently covered over by a tufa similar to that which underlies it.

It seems possible that the origin of the ore deposit was a local accumulation of manganese precipitated from spring waters. In support of this supposition it may be stated that at the town of Golconda there are, at the present time, a series of hot springs depositing a sinter highly charged with oxide of manganese. The source of this manganese in the spring waters may have been in the igneous rocks which cover large areas in the region in question, and give strong reactions for manganese. Another possible source of supply may have been in the stratified rocks already described as forming the mass of the mountain on the slope of which the deposit is situated, as both the quartzite and the limestone contain small quantities of manganese. The igneous rocks, however, contain a larger percentage of this material than the other rocks.

As regards the mode of precipitation of the manganese, it is not probable that the ore was deposited simply by the gradual desiccation of the lake waters, as was the case with the lithoid tufa enclosing it, since, if this had been so, a far more general distribution of manganese than is seen in the tufa of the Lahontan basin would be expected. It seems more probable that the

deposit was due to a local precipitation brought on by an excess of manganese in spring waters in the locality in question, and that the cause of its accumulation was the accidental formation of a suitable basin in the tufa. This basin may either have been closed or may have had an outlet into the lake. When the spring waters reached the surface they were probably retained, at least temporarily, in the basin, long enough to allow the oxidation of the metalliferous solution and the precipitation of oxide or carbonate of manganese,[1] thus causing a local accumulation of ore; whereas, if the spring water had flowed directly into the lake, its contents of manganese would have been scattered over a vast area, and would not have accumulated anywhere in deposits of noticeable size. The rock fragments in the ore and tufa represent detritus from the mountain side carried down during the deposition of the beds.

The deposition of manganese by spring waters elsewhere than in the case in question, though in limited quantities, is not an unusual occurrence. The Hot Springs of Arkansas deposit a calcareous sinter often heavily impregnated by manganese. A hot spring near the Cape of Good Hope,[2] with a temperature of 110° Fahrenheit, deposits oxide of manganese in its discharge channel. A mineral spring in the house of the Russian Crown, at Carlsbad,[3] with a temperature of 68° Fahrenheit, also forms manganiferous deposits. The springs at Luxeuil,[4] as well as the waters in some of the mines at Freyberg,[5] also form manganiferous sediments. These deposits, however, are all very small and are simply mentioned to show the frequent occurrence of manganese deposited by springs. Cases where a black incrustation of oxide of manganese is deposited by rivers and creeks on the rocks and pebbles in their courses are of common occurrence.

R. A. F. PENROSE, JR.

[1] If the carbonate was precipitated, it was later converted by oxidation into its present oxide form.

[2] Townsend, l'Institut., 1844, No. 529. (Bischof.)

[3] Kersten's u. v. Dechen's Archiv. f. Mineral., etc., Vol. XIX., p. 754. (Bischof.)

[4] Braconnot, Ann. de Chim. et de Phys., Vol. 18, p. 221. (Bischof.)

[5] Kersten's u. v. Dechen's Archiv. f. Mineral., etc., Vol. XIX., p. 754. (Bischof.)

Studies for Students.

THE ELEMENTS OF THE GEOLOGICAL TIME-SCALE.

The formations, as we find them classified in this time-scale, are arbitrarily limited and classified, but back of this arbitrary classification, certain grand events in the history of the earth are indistinctly seen. The primary units of the classification are called systems. Beginning at the base of the fossil-bearing series resting upon either Archæan or rocks of uncertain age there are first, the (1) Cambrian system of Sedgwick, restricted and also expanded as the result of later investigation. Second, the Silurian system of Murchison, divided into two, the lower Silurian which, to avoid confusion, and to give definiteness to the nomenclature has been named (2) Ordovician, by Lapworth, and the upper Silurian, for which we will retain, thus restricted, the name (3) Silurian. The fourth system, (4) Devonian, was proposed by Murchison and Sedgwick. The (5) Carboniferous system follows, which was early defined in Geology, but it is not clear who first proposed the name early applied to the coal-bearing rocks. Above this is the (6) Triassic system of Bronn, followed by the (7) Jurassic system of Brongniart. To the next system the name (8) Cretaceous was applied by Fitton. The next system still retains the name (9) Tertiary, of Cuvier and Brongniart, and is terminated by the (10) Quaternary system, whose name was introduced by Morlot. Tertiary and Quaternary were applied on the plan of Lehmann's classification which, in other respects in the course of events, has dropped out of the nomenclature.

Without explaining how the series of stratified rocks come to be divided into these particular ten systems, it may be said that their retention is due mainly to the relatively sharp boundaries

which each system exhibits in its typical locality. The systems thus serve as known and definite standards of comparison in the construction of the time-scale, as the dominance of nations or the dominance of the dynasties in each serve as time standards for the discussion of ancient human history. As the period of each dynasty in ancient history is marked by continuity in the successive steps of progress of the country, of the acts of the people and of the forms of government, and the change of dynasties is marked by a breaking of this continuity, by revolutions and readjustment of affairs, so in geological history the grand systems represent periods of continuity of deposition for the regions in which they were formed, separated from one another by grand *revolutions* interrupting the regularity of deposition, disturbing by folding, faulting and sometimes metamorphosing the older strata upon which the following strata rest unconformably and form the beginnings of a new system.

Geological revolutions were not universal for the whole earth; from which it results that these typical systems and their classification are not equally applicable to the formations of all lands. It is important also to note that the geological revolution was not a sudden catastrophe but the culmination of slowly progressing disturbances bringing the surface of the region concerned ultimately above the level of the ocean, the ocean level being a pivotal point in geological rock formation. The area whose surface is below the sea level may be accumulating deposits and making rocks, but so soon as the same region is lifted above the surface it becomes a region of erosion, destruction and degradation. Whenever, therefore, in the oscillations of level any particular part of a continental mass of the earth's crust passes permanently, or for a long geological period of time, above the sea level a great event in geological history has culminated. In case the elevation is only temporary the event is marked by unconformity or a break in the continuity of the formations; when it is permanent the geological record for that region ceases except so far fresh water deposits in lakes may continue independent record. Hence it is that these periods of revolution are of such impor-

ance in the history of the continents, and constitute the most satisfactory marks for the primary classification of geological history.

The natural geological system is a continuous series of conformable strata. A geological revolution is expressed by unconformity and more or less disturbance and displacement of the strata from their original position. The grander revolutions are also recorded in the permanent elevation of mountain masses or extensive continental areas, above the level of the sea and thus out of the reach of later strata accumulation. The most widely recognized revolution in geological time, since the close of the Archæan, separates the Carboniferous from the Triassic system. In American classification, following Dana's usage, it may be called the Appalachian revolution. It terminated the series of formations which, with only minor interruptions, had been continuously accumulating in the Appalachian basin from the early Cambrian period onward. It left above the sea level not only all the Appalachian region but the great part of the eastern half of the continent, extending westward beyond the Mississippi river to a line running irregularly from western Minnesota to Texas. This revolution produced the Allegheny mountains, and those flexings and faultings which are still recognized in the line of lesser ridges extending from Pennsylvania to Georgia. In England, Northern Europe and Northern Asia like disturbances took place at the same general period of time. In Australia, Southern Africa and South America, the indications are that the revolution was not so extensive, if it took place at all at the same time. The probabilities are that while it was almost universal for the northern hemisphere it was mainly confined to this half of the earth. The Appalachian revolution was not limited to a brief geological period but beginning near the close of the coal measures of the east it did not become effective in the region of Kansas and Nebraska till the close of the Permian. The wide extent of the disturbance of strata and consequently of records at this point in the time-scale has led to making here a primary dividing point of the scale, marking off Palæozoic time.

Several lesser, more or less local, revolutions have left their permanent mark in the grander structure of the rocks or in conspicuous geographical features of the restricted region of the continental area. The first of these was the Green mountain revolution which separated the (Lower Silurian) Ordovician from the (Upper Silurian) Silurian, for the eastern part of North America. The elevation, disturbance and metamorphism of the rocks of the Green Mountains stand forth as monuments of this event. The revolution is not sharply distinguishable in the rocks of the more southern or western regions. The second of these lesser revolutions is expressed most sharply in elevation and unconformity terminating the Devonian formations o Maine, New Brunswick and Nova Scotia, and may therefore b called the Acadian revolution. In the continental interio it may be indicated by the remarkable thinning out of th Devonian rocks toward the southwestward. In Tennesse Alabama and Arkansas they are represented by a thin sheet black shale, a few feet thick, or by but little more than line of separation between the rocks of the Silurian below and tl Carboniferous beds resting scarcely unconformably upon the This seems to indicate an elevation of the region still furth south toward the close of the Devonian, sufficient to produ extensive erosion, uncovering the Lower Silurian rocks whi were again depressed to receive the marine deposits of the ea Carboniferous upon their eroded surfaces.

The Appalachian revolution closed the Palæozoic time a left the great part of the eastern half of the continent above s level. It forms the natural interval between the Carbonifer and the overlying system, whatever that may be. Its charac teristics have already been described.

The Palisade revolution, along the eastern border of the c tinent, marks the division between the Jura-Triassic part of Mesozoic time and its closing Cretaceous age. It is expre by the trap ridges in the Connecticut valley, the Palisades other similar tracts distributed inside the coast from Nova Sc to North Carolina, and by the uptilting and in some cases f

ing of the underlying red sandstone and shale, and the resulting unconformity with the succeeding formations. The evidences of the revolution are not widely extended nor is the time relation of the termination of the revolution sharply defined, but it is sufficiently so to form a natural boundary line separating the Jura-Trias from the Cretaceous. After this point of time there occurred nothing in the eastern half of the continent which deserves the name or rank of a geological revolution. The western part of the continent is conspicuous for its grand geological construction after the Triassic at least; along the coast the Sierra Nevada revolution marked the same general interval of time recorded by the Palisade revolution of the east. These events on the opposite borders of the continent are alike at least in preceding the Cretaceous and in terminating the formations which are of Jura-Triassic age.

The Rocky Mountain revolution, which resulted in the elevation and disturbance of the rocks in the region of the Rocky Mountains, and extended from them to the border ranges, is distributed along the time from the close of the Cretaceous to the Miocene, or possibly later. It is altogether probable that the actual length of time, taken in the elevation, tilting and disturbance of strata after the last marine deposits of the pre-Laramie formations, which resulted in the permanent adding to the continent of its western third, was not longer than that consumed in the various events terminating the Palæozoic, and making into permanent land the great mass of the eastern half of the continent. This Rocky Mountain revolution resembles the Appalachian revolution, in extending over and affecting a large area of the continent, in its general upward-lifting of that area, which process extended over a long period of time, and in the great accumulation of coal or lignite which was associated with the gradual emergence of the continental mass above the sea-level.

Another feature in which the two revolutions resemble each other is found in the wide extent of the disturbances recorded. The elevation of the mountain ranges from the Pyrenees east-

ward to the Himalayas, and to the islands beyond, took place chronologically at the same general period, and that this series of disturbances may have affected the whole of the northern hemisphere is further suggested by the occurrence of gigantic erratic blocks of granite in the midst of Eocene strata in the neighborhood of Vienna and other places. Vezien (Rev. Sci. XI., p. 171, 1877) has suggested that an ice-age is indicated by these events.

This Rocky Mountain revolution marks the period of the second great break in the life of the geological ages. The Mesozoic time began with the close of the Appalachian revolution, and closed with the elevation of the Cretaceous beds above ocean-level. In our classification the division line between the Cretaceous and Tertiary was arbitrarily placed at the top of the chalk formations conspicuously developed on both sides of the British Channel. The difficulty American geologists have had in drawing the precise line to separate the Mesozoic from the Cenozoic has resulted from the change of the character of life in the beds in the western interior from marine to brackish, fresh-water and land types. This change was incident to the Rocky Mountain revolution, which had already begun, and was slowly lifting the whole region while the Laramie sediments were being laid down. Several stages may be marked in this grand revolution, but the facts connected with them are not so well-developed as to serve for general purposes of classification of the time scale.

At the close of the Miocene, a great outflow of lava in the northwestern part of the United States took place, and continued with interruptions through the Tertiary into the Quaternary time. About the Columbia River, where it cuts through the Cascade range, the basalt is over three thousand feet thick, and the outflows cover a vast extent of territory, estimated at 150,000 square miles. This was incident to the vast earth disturbance which raised to the amount of at least five thousand feet a large part of the western half of the continent.

There was, still later, a revolution which has left little record in the way of disturbance or discordance of strata, but was of

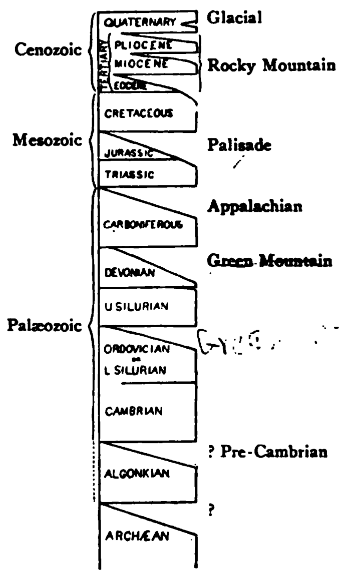
particular importance in life-history, as it introduced the recent period, or the age of man. This is the combination of events marking the glacial epoch. In general, it consisted geologically of oscillations of the northern lands for the northern hemisphere, and was associated with the accumulation of ice upon the surface and its continuance as a great ice-sheet for a long period of time. Some of the more accurate estimates of the length of geological time are based upon the rate of erosion or gorge-cutting by rivers, and the period so measured dates back to the last uncovering of the river channels coincident with the northward withdrawal of the ice-sheet. Standard examples are the estimates of the time required to cut the Niagara River gorge, and the retreat of the falls of St. Anthony from Fort Snelling to their present position, as beautifully elaborated in Winchell's Report on the Geology of Minnesota, vol. 2.

The above revolutions are selected, not as the only revolutions interrupting the regular course of sedimentary formation of stratified rocks, but as chief examples of such interruptions in the North American scale. All along the course of geological time there are evidences to show that there were constant oscillations of the relations between land and ocean-level, and at some localities these oscillations were passing across the datum plane of the ocean surface. Wherever this happened, on one side rocks were forming, and on the other erosion and degradation obliterating them as time-records. The Appalachian and the Rocky Mountain revolutions constitute the two grander revolutions. The first closed the Palæozoic life Period, the fossils being chiefly marine until the Devonian, and being associated with marine forms up to the close of the Carboniferous. The deposits are distributed across the continent, with local interruptions. After the Appalachian revolution the eastern half of the continent, except its Atlantic and Gulf borders, became permanently above the sea-level.

The period between the Appalachian and Rocky Mountain revolutions is the period of the Mesozoic life. In the faunas and floras of this period, land and fresh-water species take a promi-

nent part. The marine life is distributed over the western half of the continent and along a narrow line of formations on the Atlantic and Gulf borders. After the beginning of the Rocky Mountain revolution, the deposits of marine origin and their faunas were distributed on the marine borders of the continent as it now is, and fresh-water and land deposits were accumulated over the plains and plateaus of the western half (with few exceptions) of the continent.

Thus the grander revolutions recorded in the development of the American continent break up the geological time-scale expressed in the systems of stratified rocks into a few natural subdivisions, as may be illustrated by the following diagram:



In the use of the time-scale for the study of the history of organisms, the places marked by the revolution are those in which are found the grander interruptions to the continuity of the record. They may represent periods of great relative magnitude. They do represent periods of marked change in the faunas and floras over extensive regions. Between the grander intervals of revolution the records of life-history are relatively

continuous. There were series of successive faunas or even subfaunas, in which were expressed the general features of the evolution of life on the globe. The species preserved and known present but a very imperfect representation of the species that were living; but of those preserved in one formation there are generally found in the succeeding formations representatives of the same or closely allied genera; so that for the kinds of organisms whose remains are best preserved the record is fairly continuous for the grander rock-systems in terms of the generic, and in some cases of the specific characters.

While the conditions of deposition for a particular region remained relatively constant and uniform, the strata were accumulated in successive beds one upon another, and then the thickness of the deposits of the same kind, with proportionate thickness for deposits of different kinds, constitute a scale of definite time value; a foot of deposit representing a period of time, and the relative time-separation for two faunas would be represented by the thickness of the strata between them. It was on this principle that the time-ratios of Dana were estimated. The maximum thickness of the known strata of each geological system was taken. The limestones were assumed to represent five times the time-value that is represented by the other sedimentary deposits per foot; or in other words, every foot of limestone was estimated as equivalent to five feet of other sedimentary deposits in making up the time-ratios. On this principle Dana estimated the time-ratio for the several geological periods to be as follows:

Quaternary - - -	¼	Cenozoic 1.
Tertiary - - -	¾	
Cretaceous - - -	1	Mesozoic 3 +.
Jurassic - - -	1¼	
Triassic - - -	1	
Carboniferous - -	2	Palæozoic 12 +.
Devonian - - -	2	
Silurian (Upper) -	1¼	
Ordovician (Lower Silurian)	6	
Potsdam - - -	1	

Ward, in the fifth annual report of the United States Geological survey, has proposed to adjust these proportions as follows:

Quaternary-Recent - -	I
Miocene-Pliocene - -	I
Eocene - - - -	I
Cretaceous - - -	I
Jura-Trias - - -	I
Permo-Carboniferous -	I
Devonian - - -	I
Silurian - - -	I
Cambrian - - -	I

thus forming nine divisions of equal length.

Since Dana's estimate additions have been made to the known thickness of the Cambrian rocks of North America, which should lengthen the Cambrian ratio to 5 in the above table, and duplications of thickness due to confusion in regard to the Quebec group may reduce the Ordovician (Lower Silurian) to 5, and the Cretaceous ratio may be somewhat enlarged. The Tertiary estimate in Dana's ratios assumes the thickness to be of less ($\frac{1}{2}$) time-value because of the increased rate of deposition due to transportation of rivers. This and many other factors enter in to complicate the time-value of thickness of strata; but it must be granted that the thickness of the sediments is the prime factor in determining these time-values of the geological scale. However, the conditions of deposition, the fineness or coarseness of the clastic fragments, the abundance or rarity of supply of materials and other variable conditions must be taken into consideration in an accurate reduction of thickness of strata into length of time. Errors, also, whose value is almost impossible of estimation, arise from the intervals between strata, particularly those where unconformity exists.

After all these uncertainties are weighed the time-ratios formed on this general basis are of great importance in studying the history of organisms, and the value of accuracy in the time-scale is a sufficient reason for calling attention to the points in which greater

accuracy may be attained by further investigation. It is doubtful if it is possible with our present knowledge to reach an estimate in years or centuries, of the actual length of geological time, which is within 100 or perhaps 200 per cent. of the truth. We may accept Dana's estimate of at least 48,000,000 of years, or Giekie's of from 100,000,000 to 680,000,000. We find at one extreme the ancient theory of 6,000 years and at the other McGee's possible maximum of 7,000,000,000 years.

The rate of accumulation of sediment over the bottom of the sea may vary between the limits of one foot in 730 years and one foot in 6,800 years, as pointed out by Geikie, the figures being based upon the estimated proportion between the annual discharge of sediment in cubic feet and the area of river basins in square miles, in the case of the rivers Po and Danube. The estimate of 680,000,000 of years, quoted above, is dependent upon the assumption that the total thickness (maximum) for the sedimentary deposits is not less than 100,000 feet, and that the average rate of accumulation was not more rapid than that now going on at the mouth of the Danube, based upon Bischof's determination of the amount of sediment and matter in solution in the Danube at Vienna. It may be a query worth considering whether the estimates based upon the examination of the amount of suspended and dissolved matter in river water are not likely to err in the direction of too small amount of matter by reason of the abnormal precipitation along the course of the river incident to the presence of salts and acids put into the river by man. If the rate of the river Po were taken the length of time would be 73,000,000 of years instead of 680,000,000.

The actual length of time in years, however, is of less importance to the geologist than the relative length of time for each of the ages, and these latter, the time-ratios of Dana, are clearly deducible from the physical thickness and size of constituent particles of sedimentary rocks. Relative thickness is certainly one of the elements in the determination of the time values of the geological formation, and the fields for investigation along which greater accuracy is to be reached cover the problems of

the rate of accumulation of muds, sands and pebble beds, and of the formation of limestones, in relation to each other and under varying conditions, and the detection of the marks in the strata recording the conditions incident to the varying rates of accumulation. Until the evidence is fuller the time-ratios of Dana may be adopted as expressing approximate values for the various geological ages.

In all these studies in which the geological time-scale is applied to the evolution of the earth and its inhabitants, the time concerned is not human chronology but is what may be called *geochronology*. For this purpose we need a standard time-unit or *geochrone*. The geochrone applied in Dana's time-ratios appears to be 8,000 feet of sedimentary deposits, as in the Potsdam, (7000 feet sediments and 200 limestone). Something more definite is needed and one in which the equivalents in different kinds of deposit and in different regions can be studied and compared with some approach to accuracy. The Eocene period, as expressed in the gulf states on both sides of the Mississippi river, might be selected as a convenient and practicable standard for this purpose. Humphrey and Abbot's elaborate studies of the Mississippi river furnish minute data for comparison with recent conditions. There are 3,000 feet of marine beds referred to the Eocene in southern Europe. The Eocene or early Tertiary fresh-water beds reach a thickness of at least 10,000 feet. The Tertiary beds in Liguria are estimated to reach the thickness of 23,600 feet. If for the present we assume the Eocene geochrone to be equivalent to the maximum deposit of 3,000 feet of fragmental sediment on the edge of the continent, using Dana's estimates of time-ratios with some modifications, and adopting the term Eocene as the American students of marine Eocene apply it, the following standard time-scale for geochronology is constructed. The geochrone in this scale is the period represented by the Eocene, as understood in North America to include the marine deposits and their faunas, from the close of the Cretaceous to the top of the Vicksburg or white limestone of Smith and Johnston, 1,700 feet of which are seen in Alabama. In England it

may include the Oligocene to the top of the Hempstead beds. I realize that such a proposition furnishes many points for dispute. The scale is open for correction, and the standard may be defined with greater precision. But it is offered as a working hypothesis, to aid and stimulate investigation.

Such a standard time-scale of geochronology, on the basis of the Eocene period for a time-unit or geochrone would read as follows:

Recent, Quaternary	1	
Pliocene, Miocene	1	= 3.
Eocene	1	
Cretaceous	4	
Jurassic	3	= 9.
Triassic	2	
Carboniferous	6	
Devonian	5	
Up. Silurian	4	= 45.
Low. Silurian or Ordovician	15	
Cambrian	15	

The proximity of the Eocene of the Gulf border to continental conditions now in operation, the abundance of its marine fauna for comparison with like faunas of earlier or later age and of the same or different habitats, and its inclusion of traces of land-life for correlation with other conditions, and, in general, the wide distribution of available Eocene deposits and faunas for comparative study, are reasons for calling attention of investigators to this particular field for minute investigation in perfecting the geological time-scale.

HENRY S. WILLIAMS.

EDITORIALS.

THE United States Geological Survey is to be congratulated upon the appearance of the first atlas sheets of the geological map of the United States which, although still considered as preliminary to the regular edition, may be taken as essentially finished, and as embodying the chief features which will characterize the completed work. Each atlas consists of one portion of the whole map printed in four ways: one presenting the topography by itself; one, the areal geology; another, the geological structure by means of cross sections, and a fourth, the features of economic importance. Accompanying these are sheets of text, one of which explains certain elementary concepts of the science and defines the sense in which some of the more common terms are to be employed throughout this series of publications. The text describing the special area surveyed is admirably prepared to set forth in a concise manner the leading features of the geology and of the economic resources. It is prefaced in some cases by a general sketch of the region immediately surrounding the area published, which aids materially the comprehension of the more local geology. In one instance, however, the sketch embraces nearly the whole eastern portion of the United States, which seems unnecessary since, we assume, it is not the intention of the Survey to do away with the publication of its monographs and bulletins, where the full results of the several investigations should appear. Otherwise, the text accompanying the atlas sheets would be insufficient.

The sheets finished are from widely separated parts of the country: the Hawley sheet in Massachusetts, the geology of which is by Professor B. K. Emerson; the Kingston sheet in Tennessee, the geology by Mr. C. Willard Hayes, assisted by

Mr. M. R. Campbell; the Lassen Peak sheet and Sacramento sheet in California, the geology of the former by Mr. J. S. Diller, that of the latter by Mr. W. Lindgren. The character of the geology is equally diverse, embracing highly metamorphosed sediments in the first case, slightly modified strata in the second, and in the last two, metamorphosed igneous and sedimentary rocks associated with volcanic lavas. We notice with satisfaction the prominence given to economic features as well as the clear statement of facts regarding the dates at which the work was prosecuted, and the investigators who are to be credited with the work, two essential elements in forming a judgment as to the character of the results.

While the atlas sheets are alike in size they differ in scale from 1-250,000 to 1-62,500. The relative areas, however, are shown upon an index map on the cover of the atlas. These differences of scale are desirable because of the variable importance of the different parts of the country, and the variability in the character of the geology, which may be best represented upon maps of different scales. Such flexibility is a distinct advantage. The success of the effort to introduce greater elasticity into the method of coloring geological formations will be variously estimated. It is not possible to form a fair opinion of the merits of the system from the few examples of it furnished by the four atlas sheets already finished. But it would seem that the prominence accorded to pattern in the system, by making it a basis for the distinction of the main subdivisions of rocks: sedimentary, igneous and metamorphic, has been nullified by the lithographer, who has succeeded so admirably in reducing the lining to a mechanical minimum that the detection and recognition of patterns is a test of eyesight. We appreciate the difficulties attending the application of any comprehensive scheme of colors to so large and diversified a series of atlas sheets as that which will constitute the map of the United States, and look upon the efforts so far made as having advanced the problem without completely solving it. In the meantime the results already obtained by the geologists of the Survey in many

parts of the country should be published without waiting longer for a perfect method of coloring to be devised. J. P. I.

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Do oscillations of the crust progress by waves? Or are they limited to non-progressive vertical elevations and depressions, or to oblique thrusts and resiliences? Or are there both stationary and progressive oscillations?

The subject does not seem to have received much definite investigation, although it finds incidental expression here and there in geological literature. It is clear, however, that a determination of the stationary or progressive character of crust oscillations must have an important bearing upon the various hypotheses that concern the relations of the earth's crust to its interior. It is obvious that preliminary to a study of these problems there must be dismissed from consideration those merely apparent oscillations of the crust that are in reality but variations of the sea level. It seems quite certain, however, that when these are eliminated there remain a large class of true crustal movements. The elucidation of these is extremely difficult and would be greatly aided if it were known whether they are local or migratory, and, if migratory, whether there are any general laws governing the direction of their movements, their rate of progress, etc. If migratory, do these undulations radiate from a point of origin in all directions, like the wave circles induced upon a liquid surface, or do they, like tidal waves, creep forward in a single direction?

If we combine by free hypothesis the elevations and depressions of the Pacific coast during the Pliocene and Pleistocene times with those of the Mississippi basin and of the Atlantic coast, it is not difficult to construct a procession of elevations and depressions creeping successively across the continent. Is such a synthesis supported by any close definite data indicating progressive undulation, or is it merely an artificial combination of selected data thrown into order arbitrarily at the suggestion of an hypothesis? This illustrates a class of questions whose solution presumably leads back to crustal and sub-crustal agencies.

Another class presumably involve superficial loading and unloading, as, for example, the accumulation and dissipation of continental glaciers. These are less radical in nature and less general in applicability, but perhaps offer greater hopes of early solution. There are few problems in geology more difficult of satisfactory elucidation, even by hypothesis, than the moderate but widespread oscillations of the earth's crust. The problem of mountain building, though more obtrusive, seems really less difficult than that of plateau formation, and that of plateau formation, in turn, less unpromising than that of the common widespread crustal oscillations.

The writer has become interested in these questions in connection with some studies of the earth's crust and interior, and would welcome contributions to the subject either for publication or for personal information. T. C. C.

REVIEWS.

Monographs of the U. S. Geological Survey, vol. XVII. The Flora of the Dakota Group. A posthumous work by LEO LESQUEREUX. Edited by F. H. KNOWLTON. 256 pp., 66 plates. Washington, 1892.

The posthumous issue of this product of many years of labor, including some of the best work of one who for many years was distinguished as the highest authority in American paleobotany, is a matter of great interest to both paleontologists and biologists, since it renders the plant remains of the Dakota group, one of the oldest dicotyledon-bearing terranes, the most completely-elaborated and best-known flora, perhaps without exception, of any restricted formation in the world. Within its two hundred and fifty-six quarto pages, four hundred and sixty species are described, or, in the case of those concerning which no new observations had been made since the publication of his "*Cretaceous Flora*" and "*Cretaceous and Tertiary Floras*," enumerated with references to his earlier works. The drawings, a considerable number of which were unfinished at the time of the author's death, occupy sixty-six plates.

Of the flora, as a whole, over ninety per cent. are dicotyledons, one and three-tenths per cent. ferns, three and one-half per cent. conifers, and two and one-half per cent. cycads. In this overwhelmingly dicotyledonous flora, most of our American living tree-families have their representatives. While going over the descriptions and figures it will seem to some readers that the number of species, and particularly of varieties, is, in some instances, too great, there being for example, four varieties of *Salix proteæfolia*, seven of *Viburnum Lesquereuxii*, and fifteen of *Betulites Westii*, especially since we are left to infer in the latter case that all have the same rather indefinite habitat, "Ellsworth County, Kansas." But, while it is probably true that some of the variations do not vary more than the leaves on a single tree, still it should be borne in mind that that period in the history of the dicotyledons, soon after their first appearance in the Cretaceous, was one of immense diversity of form and great modification of character; and, although, as Professor

Lesquereux himself suggested, their differentiation might, under other circumstances, be "hazardous," yet the discrimination of the forms furnishes a better paleontological basis for the interpretation of modern types, as well as a higher degree of definition, for the use of paleontological stratigraphy.

At the close of the memoir, the broad range of the author's knowledge and paleobotanical experience is well shown in some thirty pages, devoted to an "Analysis" of the flora of the group. From this analysis, which is of great value to the biological paleontologist, he reaches the conclusions that, although but one-fourteenth of the species found in the Dakota group are also found in the Atane beds of Greenland, yet, considering the remoteness of the regions, the close relationship of the floras, and the difference in latitude, and, perhaps, in soil, the proofs are "really conclusive" of the synchronism of the two formations; "that most of the types of the arborescent flora of North America were present in that of the Dakota group, and that most of them had left remains of allied specific or generic forms in the intermediate periods," so that the flora of this continent is indigenous; and that "all the plants of the American Cenomanian, except those of Ficus and Cycads," which, he explains, may be omitted, "might find a congenial climate in the United States between 30° and 40° of latitude," a continued uniformity of climate, causing "the preservation of the original types of the flora, subjected to some modification of their original characters, without destroying them or forcing their removal by the introduction of strange or exotic forms."

Although a great proportion of the species found in any given locality are not reported from any other point, it will readily be understood why no attempt is made to work out any floral horizons in the Dakota group, when the reader observes that, while a portion of the species are reported from among a dozen localities, and a few specimens come from Minnesota and Nebraska, owing to the circumstances attending their collection and accumulation in Professor Lesquereux's hands, a large part, perhaps the greater number of them, have no more restricted habitat than "Ellsworth County, Kansas," or merely "Kansas." It is noted, however, that in one or two instances no change in the associations of the species was met in descending fifty or seventy-five feet in the series. The geological interest of the work would have been further increased if collections from the southwestern extension of the group had also been made and studied with the rest.

In the interpretation and elaboration of the author's last notes, some of which were fragmentary, and written after the lamented writer was unfit for work, as well as in interpreting and rearranging the extensive additions or modifications to the manuscript, Professor Knowlton, the editor, has shown great discretion, making no alterations or enlargements other than those necessary to the expression of the author's intended meaning, or for priority or consistency, such alterations being indicated by brief foot-notes. To him we are also indebted for a valuable tabulation of the geological and geographical distribution of the species, a compilation involving much time and consultation of the literature of the science.

It is unfortunate that those plates with washed drawings, made under Professor Lesquereux's personal supervision for the lithographer, should have, for financial reasons, been sacrificed, even though the photo-gravure work is of good quality. Much distinctness of the nervation is lost, as may be noted in a comparison with the last plates in the volume, prepared especially for the cheaper process. Although, as in too many of the paleontological publications of the United States Geological Survey, the date on the title page is earlier than the actual publication of the work, the date (1892) on the outside page is, in this instance, correct.

DAVID WHITE.

Cretaceous Fossil Plants from Minnesota. By LEO LESQUEREUX. Vol. III., Final Report on Geology and Natural History Survey of Minnesota. Feb. 15, 1893, pp. 1–22; pl. A. B.

The distinguished author of this short paper died in 1889, yet the evidences of his untiring energy are still coming to hand. This paper, bears internal evidence of having been prepared about the time of the completion of his *Flora of the Dakota Group*, which has likewise only just been published. It is prefaced by a short interesting account of the introduction and development of plant-life, illustrated by a wealth of examples and statistics.

Cretaceous fossil plants have been known from Minnesota for many years, in fact, several species were obtained by members of the Hayden survey, but this is the first complete systematic review of them. They come mostly from New Ulm, in Redwing Co., and Goodhue township in Goodhue Co. The amount of material examined was very scanty, there having been but fifty-five specimens, yet the richness of the flora is shown by the fact that there are twenty-eight species. Of this num-

ber, no less than eight are described as new to science. The new species belong to the genera Sequoia, Populus, Cissus, Alnites, Ficus, Diospyros, and Protophyllum. To these must be added four forms not specifically named, leaving sixteen species, having a distribution outside of the State of Minnesota. Of these sixteen species, fourteen are found in the Dakota group of Kansas and Nebraska, and six in the Cretaceous of Greenland, four species being common to the two localities. The species described as new, are more or less closely related to the forms from the Dakota group, or from the middle Cretaceous of Greenland, the whole serving to fix very definitely the horizon from which they came. The new, or especially interesting species are clearly depicted on the plates.

There are several obvious typographical errors as 'Kovne' for 'Kome,' 'nibrasciensis' for 'nebrascensis,' etc., which doubtless would not have occurred, had the author lived to read the proof himself.

F. H. KNOWLTON.

On the Organization of the Fossil Plants of the Coal-measures. By W. C. WILLIAMSON. Philosophical Transactions Royal Society, London: vol. 184 (1893) B. pp. 1–38; pl. 1–9.

This memoir, the nineteenth of this invaluable series, is devoted mainly to a consideration of the structure of *Lepidodendron Harcourtii.* This now classic plant was first named and described by Witham in 1833. It was also figured and described anew by Lindley and Hutton in their *Fossil Flora of Great Britain*, and was still later made the basis of an elaborate memoir by Adolph Brongniart. It was then referred by Brongniart to the cryptogams, but when he later discovered in allied forms, a secondary woody zone, developed exogenously outside of the central woody cylinder, he concluded that it must be a conifer. Williamson has long ago shown that the Lepidodendra frequently develop this secondary woody zone in mature stems, and that they are undoubted cryptogams. He was, however, unable to prove this for *L. Harcourtii*, for specimens well enough preserved to show internal structure, had not been before discovered. The present paper deals in an elaborate manner with all the authentic specimens, including the type of this species, and the author concludes that although none of the specimens were large enough to show the secondary thickening, this species is a true Lycopod, not unlike others of the genus Lepidodendron. Incidentally, the so-called genera Halonia and Ulodendron are treated of, the conclusion being that they are simply different forms of fruiting branches of Lepidodendroid and Sigillarian plants. This paper has a pronounced geological value, in that it affords a readily recognizable fossil, characteristic of a definite horizon.

F. H. KNOWLTON.

ANALYTICAL ABSTRACTS OF CURRENT LITERATURE.

SUMMARY OF CURRENT PRE-CAMBRIAN NORTH AMERICAN LITERATURE.

Prefatory Note.—The summary of current pre-Cambrian literature beginning in this number, which will continue in following numbers, though probably not consecutively, is made upon somewhat different principles from those ordinarily used. The fundamental ideas of the plan are as follows: The summary proper and the comments are kept wholly separate, in this way preventing the confusion which frequently comes from a mingling of the two. In the summaries the original language of the author is used as far as practicable, although a single sentence may be taken from several sentences of the original. Where it is disadvantageous to use the original language other words are used. This often is necessary, because the language which is adapted to complete exposition is often not the best adapted to résumé. No quotations are made; for the ideas contained, whether in the original language or not, are wholly the ideas of the author, the whole is in fact really quoted. It might be thought that better results would be reached by indicating through quotations what words are taken from the original, but this method would necessitate an unpleasant and constant alternation from quoted to non-quoted phrases. As a result of experience with the two methods, the editor feels certain that he is able more accurately and fully, in a brief space, to represent the ideas of the original author by the method proposed, than by following the usual method.

The summaries are confined to articles or parts of articles pertaining to pre-Cambrian stratigraphy. Purely economic or petrological articles are not summarized unless they concern pre-Cambrian stratigraphy, in which case the substance of the conclusions are given, rather than a full account of the observations and the manner of reaching them. The abstracts have the defects of all summaries,—a certain amount of inaccuracy, because many modifying and qualifying facts can not be given, and because undue emphasis is placed upon the conclusions.

In many cases no comments are made. This does not imply that the editor agrees with the statements of the summaries. To criticize, qualify, or refute the statements of the authors in all cases of disagreement, would often

result in extending the space taken by the comments beyond that required for the summaries. However, when the points at issue are of general interest, or fundamental importance, it is advisable to make comments and enter into discussions, even if the space taken by such comments be greater than that given to the summary of the original articles. In such comments neither commendation nor censure will be made, but the aim will be to point out the conclusions announced which fail of complete establishment, and the generalizations which appear to go beyond what is warranted by the facts published. The purpose of indicating what appears to the editor as deficiencies of these kinds is neither to put himself dogmatically in opposition to the statements of the author reviewed, nor with the belief that his opinion has more weight, but to direct attention to the questions involved, and in cases of doubt to keep them open for farther study in the field and laboratory.

Mills[1] finds in the Sierra Nevada, unconformably below the Mesozoic, eruptive granites and sedimentary slates and quartzites. The latter in places rest and were probably deposited upon the granite, while in other places they are contemporaneous and imbedded within it. The quartzites are held to be silicified phases of the slates. These rocks in age may run from Archæan to the Paleozoic and some of them may be early Mesozoic.

Darton[2] finds Ordovician fossils in the crystalline slates and schists of the Piedmont plain of Virginia, these rocks having been previously regarded as Huronian.

Lesley[3] gives a summary sketch of the pre-Cambrian rocks of Pennsylvania, the facts being taken from the detailed state reports. The Highland Belt of New Jersey and Pennsylvania; the Reading and Durham Hills; areas in Chester, Bucks, Montgomery and Delaware counties; and an area on the Schuylkill river are placed in the Archean. All are regarded as sedimentary in origin, because of the presence of marble, apatite and iron ore. The newer gneiss of the Philadelphia belt, the Azoic formations of York, Chester and Lancaster counties, and the South Mountain rocks are not definitely referred to any system. The term Huronian must be used simply as a proper and private name for a series of rocks exposed along a part of the northern boundary of the United States. Should a similar series appear in some other region and be called Huronian on account of the resemblance, the name would have no value whatever; unless we should imagine that in a so-called Huronian age the whole surface of the planet was stuccoed with a certain formation; and

[1] *Stratigraphy and Succession of the Rocks of the Sierra Nevada of California.* James E. Mills. Bull. Geol. Soc. of America, vol. 3, 1892, pp. 413–444.

[2] *Fossils in the "Archæan" rocks of Central Piedmont Virginia.* N. H. Darton. Am. Jour. Sci., 3rd series, vol. 44, 1892, pp. 50–52.

[3] *The Laurentian and Huronian Formations*, by J. P. Lesley, in A Summary Description of the Geology of Pennsylvania, Vol. 1. Rep. Penn. Geol. Sur., 1892, pp. 53–164.

received successive coats of other kinds of rock in after ages. The most dissimilar series of formations are known to be of the same age. What is happening to-day has happened in all ages. Nothing could be more unlike than the deposits now forming along the various ocean shores, and in different lakes and inland seas; yet they are all of one age. Even the deposits making in one and the same basin radically differ; as, for example, along the northern and southern sides of Lake Ontario; and along the eastern and western sides of Lake Champlain. It would therefore seem a useless task to seek for the Huronian rocks far from their native range.

Nason[1] fully describes the iron ores of the porphyry region of Missouri, and incidentally treats of the associated rocks. The porphyries usually show evidence of bedding, but this may be that of igneous flows. The Cambrian limestones and sandstones flank and rest unconformably upon the granites and porphyries. The iron ore of Iron Mountain and most of the other localities is in veins in the massive rock, probably of water infiltrated origin; or in a residuary mantle; or as concentrated detritus along the slopes or ravines of the porphyries. In the two latter cases the ore is derived from the veins. In some cases this concentration occurred before or during the deposition of the Cambrian sandstones and limestones, but in other cases is subsequent to the deposition of these rocks. At Pilot Knob the succession from the base upward is porphyry; conglomerate; a slaty ripple marked stratum in contact with the ore body; main ore body, nineteen to twenty-nine feet thick; highly ferruginous slate, one to three feet thick; heavy beds of conglomerate with an average thickness of one hundred feet. The pebbles of the conglomerate are mainly derived from the porphyries, but the regularly laminated slate and ore have a thin bedded structure, which is such as to lead to the conclusion that they are undoubtedly of sedimentary origin.

Bell[2] gives a general account of the Laurentian and Huronian systems, and a sketch of the geology of the country extending from Lake Huron northward to Lake Temiscaming, and from Lake Nipissing westward to the Spanish river. The Laurentian system is divided into an upper and a lower formation. The latter consists almost entirely of fundamental gneiss, while the upper Laurentian appears to consist of metamorphosed and sedimentary strata, to some extent at least.

The lower division of the Laurentian consists of red and gray gneiss, usually much bent or disturbed, and having generally a rudely foliated structure, and a solid or massive character. The feldspar is almost entirely ortho-

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[1] *The Iron Ores of Missouri*, by Frank L. Nason. In Rep. Geol. Sur., Missouri, for 1891-2, Vol. 2, pp. 16-69. Jefferson City, 1892.

[2] *The Laurentian and Huronian Systems North of Lake Huron, accompanied by Geological Map.* Dr. Robert Bell, Rep. of Bureau of Mines, Ontario, 1891, pp. 63-94. Toronto, 1892.

clase. The upper division of the Laurentian is more complex. It possesses more regularity in stratification and includes great banded masses of crystalline limestones, vitreous quartzites, mica-schist and hornblende-schist, massive pyroxene, and massive and foliated labradorite rocks. Considerable areas of granite and syenite occur in the formation. The Upper Laurentian of the Ottawa valley may be roughly estimated to be at from 50,000 to 100,000 feet in thickness.

While the older Laurentian rocks afford no proof of the permanent existence of the sea upon the earth, water appears to have been present, perhaps only as precipitations upon the surface, at every stage of its formation. But the deposits of limestone and tolerably pure silica in distinct bands in the Upper Laurentian afford strong support to the aqueous theory of its deposition.

With the beginning of the Huronian period great volcanic activity began, and there is evidence of the permanent abode of water on the surface of the earth. The general character of the Huronian rocks may be said to be pyroclastic, by this signifying that, although fragmental, they have nevertheless had an igneous origin.

The area mapped between the Huronian belt and the shore of Georgian bay appears to belong to the Upper Laurentian. The rocks are gneisses of the typical Laurentian varieties, finely stratified and regularly arranged in anticlinal and synclinal folds, the angles of dip usually not being far from forty-five degrees, but lesser and greater dips being found. Red and gray varieties are about in equal proportion, and they alternate with each other in thick and thin sheets. Mica-gneisses are predominant. No beds of crystalline limestone are found west of Iron Island in Lake Nipissing. Limestones are associated with the gneisses on some of the islands of the eastern part of this lake and at Lake Talon on the Mattawa. In the Parry Sound district are five distinct bands of Laurentian limestone. These rocks are classified with the Upper Laurentian rocks of the counties of Ottawa and Argenteuil.

The Laurentian rocks northwest of the Huronian belt are heavy contorted gneisses of the lower Laurentian. Associated with the gneisses are red granites which are classed with the Laurentian, but which may be really Huronian. These may have formed by softening the gneiss by heat, combined with re-crystallization, or they may be due to the alteration of the Huronian arkoses or graywackes, or they may be mainly eruptive. These granites are along the contact line between the Laurentian and Huronian. Along the line of contact between the granites and Huronian quartzites and schists, the rocks are much broken. It is not improbable that a fault exists at the line of junction between the Laurentian and Huronian rocks.

The great Huronian belt consists of a great variety of rocks, such as crystalline schists, quartzites, conglomerates, agglomerates, clay-slates, greenstones, dolomites, etc., the majority of which are pyroclastic. The rocks are

usually tilted at high angles. There are numerous instances where there is a gradual transition from the Huronion to the lower series. A few instances of local want of conformity between the two is no evidence that the two systems are not conformable on a grand scale. The few known instances where there appears to be a want of parallelism are more probably due to faulting. The pyroclastic rocks show the agency of water in their formation, and were largely derived from igneous matter, which had been more or less recently erupted. The newest rock of the Sudbury district is a volcanic breccia, which forms a continuous range of hills for a distance of thirty-six miles, with a breadth in the center of eight miles. Within the Huronian rocks are intrusive red granites.

Comments. Attention is called to the implication that the unconformity at the base of the Huronian, if it exist at all, is of a local character. The very idea of an unconformity pre-supposes that it can not be local in the narrow sense. A minor unconformity even marks a considerable time break, and when an earlier series has been profoundly metamorphosed and deeply denuded before the overlying series is deposited upon it, the break must be of regional extent, even if the contacts found are few and of small extent. It, however, does not follow that the break is universal nor even that it always extends throughout a geological basin. Space does not permit a discussion of the evidence for the existence of unconformable contacts at the base of the original Huronian in certain localities. It is enough to say that Irving, Pumpelly, Reusch, Barrois, and Tschernychew, all having seen one of the localities and the first two both, agree that the only interpretation of the phenomena at points near Garden river and near Thessalon is that of a great unconformity, not faulting as suggested by Bell, who does not appear to have ever visited these localities.

Barlow [1] states that the Huronian system is the oldest sedimentary strata of the north shore of Lake Huron, and that the Laurentian gneiss or Basement Complex is the original crust of the earth or floor on which the first sediments were laid down. This floor, as shown by the pebbles of the Huronian, was granite which had in many places a foliated or gneissic structure. In many places the subsequent folding and fracturing of the comparatively thin crust of the earth has caused large portions of the Huronian to sink below the plane of fusion, the result of which has been to produce irruptive contacts. At other places, as described by Pumpelly and Van Hise, the Basement Complex may have remained undisturbed so that the overlying detritals have not been intruded by the granitic mass beneath.

Hall and Sardeson [2] describe the Upper Cambrian rocks of Southeastern

[1] *On the relations of the Laurentian and Huronian on the North Side of Lake Huron.* Alfred E. Barlow. Am. Jour. Sci., 3d series, vol. 44, 1892, pp. 236-239.

[2] *Paleozoic Formations of Southeastern Minnesota.* C. W. Hall and F. W. Sardeson. Bulletin Geol. Soc. of America, vol. 3, 1892, pp. 331-368.

Minnesota as resting unconformably upon a pre-Paleozoic floor. The base of the Potsdam is usually conglomeratic. At Minneopa a well 800 feet deep passed through a conglomerate for a distance of 225 feet, the pebbles of which are vitreous quartzite like those occurring in Cortland, Watonwan and Cottonwood counties. A conglomerate containing granitic debris is found on Snake river about two miles above Mora, and three miles distant from the Ann River knobs of hornblende-biotite-granite, the clastic appearing to be derived from the granite. At Taylors' Falls a conglomerate made up of pebbles of diabase rests upon the diabase of the St. Croix river. These underlying formations are Archean and Algonkian rocks.

Grant[1] states that the Animikie rests unconformably upon the Saganaga granite; that the Ogishki conglomerate is intruded by the Saganaga granite, and therefore that the Ogishki conglomerate is earlier than and separated by a great structural break from the Saganaga granite. As the Keewatin has the same relations to the Saganaga granite as the Ogishki conglomerate, the same thing is true of the Animikie and Keewatin. The Ogishki conglomerate is younger than the most of the Keewatin, but is considered as a part of it.

Comments: — The most characteristic and abundant fragments in the Ogishki conglomerate are granite. The rock occurs in pieces running from those of minute size to great bowlders. It is manifest that this material was derived from a pre-existing granite. These bowlders are in all respects like much of the Saganaga granite, and the probability is very strong that this is their source. Grant is probably correct as to the intrusion of the conglomerate by a granite, but this granite may have also intruded the main Saganaga mass. The too frequent mistake has apparently been made of concluding that in the Saganaga area there is granite of but one age, when frequently in the great massives of the Northwest, granites of several ages occur, the latest ones cutting all the previous ones, and often the far newer clastics. It further follows that the implication that the Animikie is unconformably upon the Ogishki conglomerate needs the support of additional evidence. That this conglomerate is possibly more nearly related to the Animikie than to the Keewatin is shown by the presence of abundant jasper fragments, presumably derived from the Keewatin. The article appears to be another illustration of the facts being right, the author in his interpretation, however, overlooking a part of the facts which are to be accounted for in making a true generalization.

Winchell[2] gives a review of the literature on the Norian of the Northwest. Here are included the gabbros, placed as the basement member of the

[1] *The Stratigraphic Position of the Ogishke Conglomerate of Northeastern Minnesota.* U. S. Grant. Am. Geologist, vol. 10, 1892, pp. 4-10.

[2] *The Norian of the Northwest,* by N. H. Winchell. In Bull. 8, Geol. and Nat. Hist. Sur., Minn. 1893, pp. iii-xxii.

Keweenawan by Irving, and the Bohemian Mountains of Keweenaw Point. It is suggested that the anorthosites of Lawson are but facies of the gabbro, and that the two belong together in the Norian.

Comments :—This paper correlates with the so-called Norian of the East the gabbros and similar rocks of the Lake Superior region, which have heretofore been considered as constituting a part of the Keweenawan. Such lithological correlations are believed to retard, rather than advance geological progress, as they rest wholly upon unverified assumptions. The local name Keweenawan ought to be retained for the gabbros and allied rocks, or else some new local name ought to be devised for it. This latter is done by Lawson as appears from the paper next summarized.

Lawson[1] gives a petrographical and structural account of the anorthosites of the Northwest shore of Lake Superior. The anorthosite is wholly massive, completely granitic in structure, and is composed almost wholly of basic feldspar, varying in composition from labradorite to anorthite. The rock occurs near Encampment Island, in the vicinity of Split Rock point, at Beaver Bay and vicinity, at Baptism river, on the slopes of Saw Teeth mountain, and at Carlton Peak. In nearly all of these localities the rock is found in rounded dome shaped masses below the other eruptives of the coast. It is cut by these different eruptives, and in the lava flows are found very numerous blocks and bowlders of anorthosite, which were caught in at the time of their extrusion. These facts show that the anorthosite is of pre-Keweenian age, and since the anorthosite is a plutonic rock, it must have suffered profound erosion prior to the extravasation of the Keweenian eruptives. Norwood, Irving and Winchell have described the blocks of anorthosite in the lavas at some of the points. Winchell regarded the anorthosite at Split Rock as older than the eruptives containing masses of them, and Irving reached the same conclusion in reference to the anorthosite at Carlton Peak. However, none of them differentiated the anorthosite mass from the general aggregation of volcanic flows, constituting the Keweenian series of the Minnesota coast. The surface of the pre-Keweenian anorthosite is domed and hummocky like that of the other Archean terrains of Canada, and it is thought to have been only modified by Pleistocene erosion. The interval between the anorthosite and the Keweenian is probably the same as the pre-Paleozoic interval which effected the reduction of the Archean to the great hummocky plain, to which it was reduced before the Animikie was deposited upon it. As the Keweenian rests directly upon the anorthosite, the Animikie is absent for the middle third of the Minnesota coast. Irving places the thickness of the Keweenian of the area at 20,000 feet, stating that it may reach 22,000 or 24,000 feet. The maximum thickness of the

[1] *Anorthosites of the Minnesota Shore of Lake Superior*, by A. C. Lawson. In Bulletin 8, Geol. and Nat. Hist. Sur., Minn., 1893, pp. 1–23.

Keweenian is not more than one-tenth of this thickness. Irving's subdivision of the Keweenian into groups, and his estimate of the thickness of various portions of the series are of little value; a statement which it is as painful to make as it is necessary in the interests of sound geology. The anorthosite is provisionally correlated with the Norian of the Province of Quebec, but as this correlation is merely a hypothesis, the name Carltonian is suggested for this formation.

Comments:—The main structural conclusion of Lawson, that the anorthosite of the Northwest shore of Lake Superior is older than and was deeply eroded before the deposition of the upper Keweenawan lava flows, seems clearly established, and this is a conclusion of great importance. However the general inferences which are drawn from this relation call for more evidence.

At the outset it is to be noted that the term Paleozoic is extended to include the Kewèenian and Animikie series, a usage not followed by many and involving a great proposition which demands evidence. The question is, however, too large to discuss here.

The Keweenaw series of Northeastern Minnesota is of great extent and thickness. Irving, in his latest paper on the pre-Cambrian divided the Keweenawan into two divisions, a lower basal gabbro, and an upper series, consisting of thinly-bedded basic and acid rocks.[1] The anorthosite is but a facies of gabbro, in which the pyroxenic constituent is reduced to a minimum. The most probable explanation of the relations made out by Lawson, as it appears to me, is that the anorthosite exposed on the coast belongs with this great basal gabbro, and this is the position which is apparently favored by Professor Winchell,[2] although he regards the whole gabbro mass as pre-Keweenawan. This latter is a matter of definition, and is contrary to the general usage of the term in the past, both divisions having been generally regarded as making up the Keweenawan. The length of the period represented by the Keweenawan was so great, that after the outflow or intrusion of the basal gabbro there may have been along the Minnesota coast a period of erosion, thus cutting deep into the gabbro, anorthosite and associated rocks. Later in Keweenawan time this eroded surface was covered by the flows of the upper division. Indeed this unconformity between the basal gabbro of the Keweenawan and the upper, more thinly-bedded members of the series was noted by Irving[3] both for the Bad River area of Wisconsin and for Minnesota, and is

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[1] *The Classification of Early Cambrian and pre-Cambrian formations*, by R. D. Irving. In 10th Annual Rep. U. S. G. S., pp. 418–420.

[2] *The Norian of the Northwest*, by N. H. Winchell. In Bull. Nat. Hist. and Geol. Sur., Minn., pp. 28, 19.

[3] *Copper Bearing Rocks of Lake Superior*, by R. D. Irving. In Third Annual Rep. of Director U. S. G. S., pp. 134, 136, 137. Also Mon. 5, U. S. G. S., pp. 155, 156, 158, 159.

reinforced in the latter case by his map of Northwestern Minnesota, which suggests that the upper division of the Keweenawan overlaps the lower unconformably.

In the first of these areas the thin-bedded flows are described as being poured out against the gabbro mass, which, it is said, must have stood to a great height, until finally the flows accumulated sufficiently to cap the upper surface of the gabbro. So strongly was Irving impressed by these facts, that he states that he was inclined at first to place the gabbros of the Bad River district with the Huronian, and to regard them as the equivalents of the great flows of the Animikie series of Thunder Bay, but, finding the Animikie slates unconformably under the gabbros, he preferred to put them as the earliest division of the Keweenawan, clearly recognizing that there was a very considerable unconformity between these coarse, massive rocks and the later thinly-bedded ones. This reference was made because of the close lithological relationship of the gabbro and the Keweenawan diabases, and because in eruptive series such breaks were regarded as less significant.

It thus appears that Irving fully appreciated an unconformity, probably at the horizon of Lawson's unconformity, but he did not recognize that the break which has so extensive an occurrence also exists along the Minnesota coast. If the explanation suggested as to the relations on the Minnesota coast be true, Irving's statements, used in reference to the Bad River area, can be applied almost exactly to this one, in which case the difference between Irving and Lawson is that of nomenclature. Lawson restricts the term Keweenawan to the upper part of the series, whereas Irving and other writers regarded the Keweenawan as including both divisions. It also follows, if the anorthosite is Keweenawan, that Lawson's conclusion that the Animikie is absent below the Keweenawan in Northeastern Minnesota, is without foundation, for the base of the Keweenawan thus defined is not here exposed. Further, the Animikie is certainly unconformably below the great basal gabbro of Minnesota. It further follows that the correlation of the anorthosites of Lake Superior and those of the Province of Quebec has no value. But, wholly apart from the stratigraphy of Northeastern Minnesota, I must confess to a complete lack of confidence in the correlation of eruptive rocks so far removed as these.

To the statement that Irving's subdivision of the Keweenawan into groups and his estimate of the thicknesses of various portions of the series are of little value, I feel that I must take exception. The painstaking character of all of Irving's work is well-known. He spent many years of study upon the series in Michigan and Wisconsin. His study, and that of his assistants, Messrs. Chauvenet, Cambell and McKinley, on the northwest coast of Lake Superior was of a detailed character. It would seem scarcely possible that Dr. Lawson's study of the stratigraphy in a single trip, in which he made no attempt to re-measure the sections (so far, at least, as can be ascertained from his paper) could have been detailed enough to warrant this sweeping state-

ment. On one point Irving seems not to have fully drawn the conclusion which legitimately followed from his observations. This, however, does not invalidate the observations in any way, nor lessen the strength of the many important conclusions which were reached. The only particularized notice by Dr. Lawson of these supposed errors is in reference to the thickness of the Keweenawan. The statement that Irving overestimated this thickness tenfold certainly needs additional justification. The thicknesses given are maxima for the particular region. Irving was perfectly well aware that the Keweenaw series varies greatly in thickness from place to place, being largely of volcanic origin. He also knew that it varies from its maximum thickness to entire disappearance at a not very remote distance from the Lake Superior basin. That a volcanic series is not of great thickness in one particular area of a region is no evidence that it is not so in other parts. If the anorthosite division of the Keweenawan constituted a mountainous mass for the central part of the Minnesota coast, and the upper Keweenawan beds were deposited against them, as before suggested, these later beds may have a very great thickness remote from the anorthosites, or at the inaccessible base of the past mountain range, and this would be quite in accordance with a moderate thickness near the tops of the anorthosite domes.

Lawson[1] describes the laccolitic sills of the northwest coast of Lake Superior. The trap sills are mainly diabases, but they occasionally pass into gabbros. It is held that there are no contemporaneous volcanic rocks in the Animikie group, and that the trap sheets are intrusive in their origin, rather than subsequent volcanic flows, for the following reasons: They are simple geological units, one not overlapping another; they have a uniform thickness over areas more than 100 square miles in extent; where inclined, the dip is due to faulting and tilting; they have no pyroclastic rocks associated with them; they are not glassy nor amygdaloidal; they show no flow structure, or other distinct properties of effusive rocks; their contacts with the slates are sharp; they never repose upon a surface which has been exposed to weathering or erosion; they are analogous to the great dikes of the region in all their relations; they may be observed in direct continuity with dikes; they pass from one horizon to another; they have a columnar structure extending throughout their thickness; apophyses pass from the main sheets into cracks of the slate above and below; they locally alter the slates above and below them.

The Animikie strata have been dislocated by a great system of faults, the orographic blocks having been frequently tilted. The non-recognition of this prevalent tilted structure has led to very excessive estimates of the thickness of the series by Irving and Ingalls. In the vicinity of Black Sturgeon River

[1] *The Laccolitic Sills of the Northwest Coast of Lake Superior*, by A. C. Lawson. In Bull. 8, Geol. and Nat. Hist. Sur., Minn., pp. 24–48.

and on the Isles of Nipigon Bay are numerous places where Keweenian strata are capped by thick sheets of trap, identical with those which cap the Animikie, but, though these sheets cannot be traced in absolute continuity in the interval, there are many outlying patches which fill the gap. The same trap sheets are found in several instances to pass from the Animikie to the Keweenian, and there are the same evidences of intrusion of independent trap sheets in the Keweenian that are in the Animikie. These rocks are, therefore, of post-Keweenian age, and, to discriminate them from the Keweenian and Animikie, they are designated the Logan sills.

Comments :— The fact that all the trap sheets of the Animikie studied by Lawson are intrusive is no evidence that in other areas, not studied by him, there may not be contemporaneous volcanics. The traps in the Triassic of Connecticut and New Jersey are an illustration of this point, a part of them being extrusive and a part intrusive. Also in the Penokee series, the equivalent to the Animikie series, while for the main part of the area there are no contemporaneous volcanics, in the eastern end of the series there suddenly appears a great thickness of contemporaneous volcanic fragmentals, and such may occur in the Animikie in the areas not yet studied.

The inclination of the Animikie series was fully recognized by Irving and Ingall, and this it was which led them to make their estimates of the thickness. The statement, that the strata have been dislocated by a great system of faults, may be true, but in the paper it is not supported by any evidence; and, until detailed evidence is presented, the conclusion of Irving and Ingall as to the thickness seems more probably true than the hypothesis of numerous faults.

Because the sills are later than the Animikie and Keweenawan strata which they have intruded, is no sufficient evidence that they are post-Keweenawan. The thickness of the Keweenaw series is so great that it is quite reasonable to expect that correlative with the later extrusions were intrusions between the older Keweenawan strata. To explain all the facts cited on the northwest coast it is only necessary to suppose that the upper part of the Keweenawan has been removed by erosion, and that the sills now composing the upper layers in these places were overlain at one time by higher members, which have subsequently been removed by erosion. This is not a violent supposititition, for it is well known that erosion and volcanic extrusion alternated many times in single areas during Keweenawan time.

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(*Further acknowledgments of pamphlets already received will be made in the next number.*)

THE

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ON THE TYPICAL LAURENTIAN AREA OF CANADA.

THE name Laurentian was given by Logan in 1854 to the great series of rocks forming the Laurentides or Laurentian Mountains, a district of mountainous country rising to the north of the River and Gulf of St. Lawrence, and extending in an unbroken stretch along the shore of the latter from Quebec to Labrador, a distance of nine hundred miles. This district, with its continuation to the west as far as Lake Huron, being situated in the Province of Quebec and the adjacent portion of the Province of Ontario, and forming part of the main Protaxis of the continent, is the "Original Laurentian Area" of Logan. The Laurentian rocks are now known to extend far beyond the limits of this area to the west and north, constituting, as they do, by far the greater part of the Protaxis, and underlying (with subordinate patches of Huronian) an area of somewhat over two million square miles.[1] The area above referred to is, however, the one which was first studied and described; it is the "Typical Laurentian area," and to it the observations in the present paper will be as far as possible confined.

A general exploration of the area in question, and a more detailed study of a small part of it—the Grenville District—situated in the counties of Argenteuil and Terrebonne in the Prov-

[1] Accepting the distribution of the Laurentian in the far north, given by Dr. G. M Dawson, as correct, the area is 2,001,250 square miles. This does not include the outlying and separated areas occurring in Newfoundland, New York State and Michigan.

ince of Quebec, was carried out by Logan and his assistants in the early years of the Canadian Geological Survey. An excellent résumé of the results of these studies is given in the "Geology of Canada," published in 1863, which contains not only a good description of the general petrographical character and arrangement of the rocks which make up the area, but is accompanied by an atlas containing two maps illustrating this description, one showing the general distribution of the Laurentian in the eastern part of the Dominion, and the other its stratigraphical relations in the smaller area above referred to.

As a result of these studies, Logan announced his belief that the Laurentian System consisted of two great unconformable series of sedimentary rocks, to which he gave the names Upper and Lower Laurentian. The latter he considered to be divisible into a lower and an upper portion, which sub-divisions he regarded as probably conformable to one another. In the course of time these several series came to be known as the Anorthosite or Norian Series, the Grenville Series and the Fundamental or Ottawa Gneiss. Logan's views may then be represented as follows:

Anorthosite or Norian Series,	Upper Laurentian.
Grenville Series,	Upper portion } Lower Laurentian.
Fundamental or Ottawa Gneiss,	Lower portion } Lower Laurentian.

Subsequently, in the southeastern corner of the Province of Ontario, in the district lying to the north of the eastern end of Lake Ontario, another series of rocks was discovered—the so-called Hastings Series. Logan supposed this to come in above the Grenville Series, while Vennor, who subsequently examined the district, believed it to be equivalent to the lower part of the Grenville Series already mentioned.

When these investigations were carried out, the microscope had not as yet been seriously employed in petrographical work. The precise composition of many of the rocks making up the several series was not recognized, the effects produced by great dynamic action were not duly considered, and the foliation possessed in a high degree by some and to a certain extent by almost all these

rocks was considered, in all cases, to be a more or less obliterated survival of original bedding. The detailed mapping in the field, accompanied by microscopical work in the laboratory, by which alone conclusive results can be obtained in working out the structure of complicated areas of crystalline schists, was not carried out, in fact in many districts the construction of detailed maps was at that time practically impossible. It is not surprising therefore that, although excellent in the main, some of the results arrived at have since proved to be erroneous.

It is proposed, in the present paper, to place before the readers of this JOURNAL in as brief a manner as possible, a general account of the several series of rocks occurring in this area, and to point out what, in the opinion of the present writer, seems to have been satisfactorily established concerning the statigraphical position and mutual relations of these ancient rocks and what still remains to be determined by further study, and in conclusion to give a short sketch of the evolution of this portion of the continent.

The Fundamental Gneiss.—Exposed over very wide stretches of country in Canada, and making up in all probability by far the larger part of the Archean Protaxis, is the "Fundamental Gneiss," sometimes called, from its great development about the upper waters of the Ottawa River, the "Ottawa Gneiss." It is composed essentially of orthoclase gneiss, usually reddish or greyish in color. Of this there are a number of varieties, differing from one another in size of grain, relative proportion of constituent minerals and in the distinctness of the foliation or banding. It is sometimes rich in quartz, while at other times this mineral is present in but very small amount. It is usually poor in mica and bisilicates. Dark bands of amphibolite are not uncommon, while basic hornblende or pyroxene gneisses occur in some places. Other schistose rocks are rarely found. Over great areas it is often nearly uniform in character and possesses a foliation which can only be recognized when exposures of considerable size are examined. On this account it is often referred to as a granitoid gneiss, a designation, however, which by no

means accurately describes it as a whole. At a locality cited by Sir William Logan, as one where it is typically developed, namely, Trembling Mountain in the above mentioned Grenville Area, it consists of a fine grained reddish orthoclase gneiss, with distinct but not very decided foliation, containing here and there bands of orthoclase gneiss of somewhat different character, as well as bands or layers of a dark amphibolite.

How much of this Fundamental Gneiss really consists of eruptive material is not known. The indistinct foliation, in many cases at any rate, is not a survival of original bedding, but is clearly due to movements in a plastic mass. It is often possible to recognize the existence of an indistinctly foliated gneiss intruded into more distictly foliated gneiss. The gneiss, in some cases, shows excellently well-marked cataclastic structure, while in other cases this is not distinct. The evidence accumulated goes to show that the Fundamental Gneiss consists of a complicated series of rocks of unknown origin, but comprising a considerable amount of material of intrusive character.

The Grenville Series.—In certain parts of the Laurentian area, and notably in the Grenville district before mentioned, the Laurentian has a decidedly different petrographical development. Orthoclase gneiss is still the predominating rock, but it presents a much greater variety in mineralogical composition, and is much more frequently well foliated, often occurring in well defined bands or layers like the strata of later formations.

Amphibolites are abundant, also hornblende schists, heavy beds of quartzite and numerous thick bands of crystalline limestone or marble, all these rocks being interbanded or interstratified with one another. In the vicinity of the limestones the variety in petrographical character is especially noticeable; garnets often occur abundantly in the gneiss, the quartzite and the hornblende schist, as well as in the limestone itself, beds of pure garnet rock being found in places. Pyroxene, wollastonite and other minerals are also abundant, while the presence of graphite disseminated through the limestones and their associated rocks, often in such abundance as to give rise to deposits of economic

value, is of especial significance. This mineral which is not found in the Fundamental Gneiss, occurs usually in little disseminated scales but occasionally in veins. The limestones are thoroughly crystalline, generally somewhat coarse in grain and often nearly pure. They usually, however, contain grains of serpentine, pyroxene, mica, graphite or other minerals, of which over fifty species have been noted. They are often interstratified in thin bands with the gneiss, in places are very impure, and may be traced for great distances along the strike, being apparently as continuous as any other element of the series. This development of the Laurentian is known as the Grenville Series, and has been considered by all observers to be above and to rest upon the Fundamental Gneiss. In it are found all the mineral deposits of economic value—apatite, iron ore, asbestos, etc., which occur in the Laurentian. The rocks of this series, though generally highly inclined, over some large areas lie nearly horizontal or are inclined at very low angles, but even in such cases they show evidence of having been subjected to great pressure, resulting in some cases in the horizontal disruption of certain of the beds.

The areas occupied by the Grenville series although of very considerable extent, being known to aggregate many thousand square miles, are probably small as compared with those underlain by the Fundamental Gneiss. The relative distribution of the two series has not been ascertained except in a general way in the more easily-accessible parts of the great Archean Protaxis. The Grenville series is known to occupy a large part of its southern margin between the city of Quebec and the Georgian Bay, while the discovery of crystalline limestone in the gneiss elsewhere at several widely separated points, as for instance on the Hamilton River in Labrador, in the southern part of Baffin Land and on the Melville Peninsula, makes it probable that other considerable areas will, with the progress of geological exploration, be found in the far north. Over the greater part of the Protaxis, however, the more monotonous development of the Fundamental Gneiss seems to prevail.

The question of the origin and mutual relations of the Fundamental Gneiss and the Grenville series is one about which, though much has been written but little is known. Three views may be taken on the matter—

(1) The Fundamental Gneiss may be supposed to contain what remains of a primitive crust, penetrated by great masses of igneous rock erupted through it—the whole having been subjected to repeated dynamic action.[1] The Grenville Series may be an upward continuation or development of the Fundamental Gneiss under altered conditions, marking in the history of the world the transition from those conditions under which a primitive crust formed to those in which sedimentation under the present normal conditions took place. It would seem that if the earth originally had a crust on which the first sediments were deposited when the temperature became sufficiently low to permit water to condense, that the said water, at a very high temperature and under what are to us now inconceivable conditions but little removed from fusion, might give rise to sediments not altogether similar to those formed by the ordinary processes of erosion at the present time. Also that, under the unique conditions which must have prevailed at that early time, in the formation of a crust solidification, precipitation and sedimentation might go on to a certain extent concomitantly, and thus no well-defined break could be detected, or would in fact exist, between a primitive crust formed by solidification from a fused magma and the earliest aqueous sediments or deposits. The Fundamental Gneiss and the Grenville Series might thus, as Logan supposed, form one practically continuous series and represent parts of the original crust, with the first crystalline or clastic sediments deposited on it, the whole penetrated by eruptive rocks and folded up and altered by repeated dynamic action at subsequent periods.

The general petrographical similarity of the two series, taken in connection with the more varied nature of the Grenville Series,

[1] See also, The Geological History of the North Atlantic, by Sir William Dawson, Presidential Address, B. A. A. S., 1886.

its frequent stratified character, and the presence in it of limestones and graphite indicating an approach to modern conditions and the advent of life, together with the difficulty of clearly separating the two series from one another and defining their respective limits, lends support to this view.

(2) A second view is that the Grenville Series is distinct from the Fundamental Gneiss reposing on it unconformably and of much more recent age; that it consists of a highly altered series of clastic origin—the Fundamental Greiss having possibly some such origin as that mentioned under the last heading, or representing a much older series of still more highly altered sediments. This is supported by the fact that some observers have thought they could in places trace out a line of contact between the two. But in these cases it always becomes a matter of serious doubt whether what has been considered to represent the Fundamental Gneiss is not really a mass of intrusive rock, in which, by pressure or motion, a somewhat gneissic structure has been induced. If the Fundamental Gneiss, moreover, was ever an ordinary sediment, it must have undergone a metamorphosis so profound that no trace of clastic origin remains, unless the generally indistinct foliation or banding of some portions of it be considered as such. It must also be noted in this connection that, although the rocks of the Grenville series are more frequently possessed of a decided foliation and are often banded, bands of different composition alternating with one another as in ordinary sedimentary deposits, and although in this series crystalline limestones and quartzites occur, we have as yet no absolutely conclusive proof that even they are of sedimentary origin. The series is thoroughly crystalline, most of its members at least show the effect of great dynamic action, and so far as the present writer is aware, no undoubted conglomerate or finer grained rock showing distinct clastic structure has ever been found. In view of this fact,—although the series is, in all probability, made up in part at least and perhaps wholly of sedimentary material,—the proposal to separate it from the rest of the Laurentian and class it as Algonkian or Huronian seems at least premature.

(3) A third view which has been advanced is that the Fundamental Gneiss is nothing more than a great mass of eruptive granite or granitic rock which has eaten upward, and in places penetrated the Grenville series, or perhaps absorbed it, while the Grenville series itself represents a series of highly altered sediments of Laurentian, Huronian or subsequent age. The enormous extent and world-wide distribution of the Fundamental Gneiss forming as it does wherever the base of the geological column is exposed to view, the foundation or floor on which all subsequent rocks are seen to rest, is opposed to this view of its origin, as is also its persistent gneissic or banded character, although, as above mentioned, much eruptive material is undoubtedly to be found in it.

Which of these views is correct can be ascertained only as very careful and detailed mapping, accompanied by accurate petrographical study, is proceeded with. In the present state of our knowledge additional argument and discussion will not help us toward the goal, while hasty work and generalization serves but to retard the progress of our knowledge.

The Anorthosite Series.—Associated with both the series of rocks just described there are, as has been mentioned, great eruptive masses of granite, some of which have been folded in with the gneisses, while others evidently erupted at a much later date, show no trace of dynamic action.

In addition to these, basic eruptive rocks belonging to the gabbro family occur in certain districts, sometimes in the form of comparatively insignificant masses, but elsewhere underlying great tracts of country. One on the upper waters of the Saguenay has an area of no less than 5,800 square miles. These usually consist of a variety of gabbro in which the magnesia-iron constituents are present in very small amount, being in many cases entirely wanting, so that the rock consists practically of pure plagioclase feldspar. These rocks were called *anorthosites* by Hunt, in the early reports of the Canadian Geological Survey, on account of the great preponderance in them of "Anorthose,' a general name given many years ago by Delesse to the triclinic

feldspars, as distinguished from "Orthose," or orthoclase feldspar, and thus equivalent to the term plagioclase now in general use, but having no connection with anorthite, a variety of plagioclase which is seldom present. After a careful study of these rocks, both in the field and the laboratory, it is believed that this name should be retained for this well-marked member of the gabbro family, which, though not a common rock elsewhere, has an enormous distribution in the Laurentian of Canada.

If an olivine gabbro be regarded as the central member, so to speak, of the gabbro family, the replacement of the monoclinic by rhombic pyroxene will give rise to an olivine norite. A gradual diminution in the amount of plagioclase will give rise to a peridotite or gabbro pyroxenite, a diminution in the amount of pyroxene to a troktolite or plagioclase-olivine rock, while a diminution in the amount of olivine and pyroxene will give rise to an anorthosite, which variety forms the greater part of the intrusive masses in question. The gradual passage of one variety into another can be distinctly traced in many localities in the anorthosite masses. These anorthosites are in some places massive, but very frequently show a distinct foliation, often very perfect. In some places they occur interbanded with the gneiss and crystalline limestone, while elsewhere they cut directly across the strike of these rocks. The interbanded anorthosite, together with the gneiss and limestone associated with it, was supposed by Logan to form a distinct sedimentary series, to which the name "Upper Laurentian," or "Norian," was given, because the discovery that elsewhere the anorthosite runs across the strike of the gneiss was supposed to indicate that this series covered up and unconformably overlay the Grenville series, the igneous and intrusive character of the anorthosite not being recognized on account of its frequently foliated structure. It is now known that these anorthosites do not constitute an independent formation, but are igneous rocks which occur, cutting both the Grenville series and the Fundamental gneiss. They have, however, in many cases been intruded before the cessation of the great dynamic movements to which the Laurentian was

subjected in pre-Cambrian times, and thus frequently taking a line of least resistance and having been intruded between the bands or strata of the Grenville series, have had a foliation induced in them parallel to that of the gneiss, while in other cases where they are more or less massive, they cut across the the strike of the latter.

In many cases the anorthosites which exhibit a perfect foliation may be traced step by step into the massive variety, the gradual development of a foliated structure in the rock being accompanied by a progressive granulation of the constituents, most beautifully seen under the microscope. The change, however, differs from any hitherto described in that it is purely mechanical. There are no lines of shearing with accompanying chemical changes, but a breaking up of the constituents throughout the whole mass, though in some places this has progressed much further than in others, unaccompanied by any alteration of augite or hypersthene to hornblende, or of plagioclase to saussurite, these minerals, though prone to such alteration under pressure remaining quite unaltered, suffering merely a granulation with the arrangement of the granulated material in parallel strings. This process can be observed in all its stages, and there is reason to believe that it has been brought about by pressure acting on the rocks when they were deeply buried and very hot.[1] The anorthosite areas, of which there are about a dozen of great extent with many of smaller size, are distributed along the south and southeastern edge of the main Archean Protaxis from Labrador to Lake Champlain, occupying in this way a position similar to that of volcanoes along the edge of our present continents. Curiously enough precisely similar occurrences of this anorthosite have been found in connection with similar gneissic rocks, supposed to be of Archean age, in Russia, Norway and Egypt. These anorthosite rocks being intrusive, may be left out of consideration in endeavoring to work out the succession of the Archean in this great area.

[1] See FRANK D. ADAMS—"*Ueber das Norian oder Ober-Laurentian von Canada,*" *Neues Jahrbuch für Mineralogie, etc., Beilageband VIII., 1893.*

The whole Laurentian system, including the anorthosites, is in many places cut by numerous dykes of large size, which can often be traced for great distances. These are of several kinds, the principal series consisting of a beautiful fresh diabase often holding quartz in considerable amount in micro-pegmatitic intergrowths with plagioclase. Other sets of dykes and eruptive masses consisting of augite and mica syenites, quartz-porphyries and other rocks are also known to occur but have not as yet been carefully studied.

The Hastings Series.—The stratigraphical relations of the Hastings series have not as yet been satisfactorily determined. The rocks constituting the series differ widely in petrographical character from those of the Fundamental Gneiss and the Grenville series, both of which are supposed to occur in its immediate neighborhood. The series consists largely of calc-schists, mica-schists, dolomites, slates and conglomerates, thus containing much material of undoubtedly clastic origin. It has moreover a very local development, being confined, so far as at present known, to one small corner of the area, as has been mentioned. It was by Logan supposed to come in above the Grenville series, while Vennor who subsequently examined the district, believed it to be equivalent to the lower part of this series. That we have in the Hastings series a comparatively unaltered part of the Grenville series, made up largely of rocks whose origin is easily recognized, would be a most important fact if established, and would, of course, afford a key to the whole question of the origin of the latter. This is a conclusion, however, which cannot be accepted until supported by very clear and decisive evidence, especially as the stratigraphy of the Hastings district is very complicated, the several series represented in it being much folded and penetrated by great masses of eruptive rocks. The whole district has also been subject to great dynamic action, some of the pebbles in the conglomerates of the Hastings series being distorted in a most remarkable manner. This series may prove to be merely an outlying area of Huronian rocks folded in with the Laurentian, and until the district has been studied in

detail its stratigraphical position must remain a matter of conjecture.

Leaving the Hastings series out of consideration therefore, we have in this Original and Typical Laurentian area two developments of the Laurentian, generally considered as constituting two series, namely the

Grenville or Upper series,
Fundamental, Ottawa, or Lower Gneiss.

The Evolution of the Area.—In endeavoring to outline the main events in the evolution of this area it will be necessary to extend the limits of our observation somewhat and seek for evidence bearing on the question in other parts of the Protaxis, where we meet with developments of Huronian and various earlier Paleozoic strata not found in the typical area itself.

From the highly contorted condition of the Laurentian rocks of this area as well as from the abundant evidences of dynamic action which they present both in the field and under the microscope, it is evident that they have been subjected to great orographic forces, which in very early times threw them up into mountain ranges, probably of great height. Some of the associated eruptive rocks were intruded before these movements began, or while they were in progress and have accordingly been influenced by them, while others, having been intruded later, have not been affected.

How high these mountains rose cannot of course be determined. Bell states that some of the mountains on the Labrador coast now rise to a height of from 5,000 to 6,000 feet, while Lieber has estimated that on the coast of Northern Labrador they rise to a height of from 6,000 to 10,000 feet. Along the southern part of the Protaxis, where the country is much lower, notwithstanding the enormous subaerial denudation and glaciation which the area has repeatedly undergone, there are many points still rising from 2,500 to 3,500 feet above sea level, while Logan estimated that the average elevation is from 1,500 to 1,600 feet. In the Adirondacks, which are but an outlying portion of this area, there are elevations of over 5,400 feet.

The high elevations attained by these rocks in portions of the Protaxis in the north may, of course, be due to differential elevation, but immediately along the southern edge of the area there can have been but little differential change of level as compared with the flat-lying Potsdam strata which border it and lie but little above the present sea level. Further evidence of the original height or continued uprising of the area is afforded by the fact that all the material of which the North American continent was built up (with the possible exception of some of the limestones) was derived originally from the Archean Protaxis of the continent, a considerable proportion of this at least coming from the main Protaxis of which this typical Laurentian area forms a part. We must conclude therefore that in early Cambrian or pre-Cambrian times, in portions of the Protaxis at least, the Laurentian mountains rose several hundred and possibly in places several thousand feet above the sea level.

The intrusion of the granites and anorthosites as well as the folding of the whole system of rocks took place before Upper Cambrian times. The whole series was moreover without doubt at that time in the "metamorphic" condition in which we now find it, for along the margin of the area the Potsdam sandstone rests in flat undisturbed beds on the deeply eroded remnants of these old mountains, its basal beds often consisting of a conglomerate with pebbles of the underlying gneissic rocks. These Cambrian strata cover up the gneisses, granites and anorthosites alike and are evidently of much more recent age, being separated from the Laurentian by the long interval occupied in the upheaval and erosion of the Laurentian area.

How long before Upper Cambrian times this folding and erosion took place cannot be determined from a study of this area, but further west along the edge of the Protaxis in the Lake Superior district we find that the Keweenawan, Nipigon and Animikie Series also repose in flat undisturbed beds on the eroded remnants of a series of crystalline rocks which have the petrographical character of the Fundamental Gneiss. This

makes it at least very probable that in this eastern area also the erosion took place in pre-Cambrian times.

It is a very remarkable fact that the roche moutonné character possessed by these eroded Laurentian rocks and which is usually attributed to the glaciation which they underwent in Pleistocene times, was really impressed upon them in the first instance in these pre-Cambrian times, for all along the edge of the nucleus from Lake Superior to the Saguenay, the Paleozoic strata, often in little patches, can be seen to overlie and cover up a mammillated and roche moutonné surface showing no traces of decay and similar to that exposed over the uncovered part of the area. The conclusion therefore seems inevitable that not only were these Laurentian rocks sharply folded and subjected to enormous erosion, but that they had given to them in pre-Cambrian times their peculiar hummocky contours so suggestive ot ice action.[1] The pre-Paleozoic surface of the Fundamental Gneiss of Scotland, as Sir Archibald Geikie has shown, also presents the same hummocky character.[2] On this surface the Upper Huronian, Cambrian, and later Paleozoic rocks were deposited.

To what extent the seas of Cambrian, Silurian and Devonian times passed over this area cannot be determined with certainty. A great series of rocks referred to by Dr. G. M. Dawson as probably of Lower Cambrian age and analogous in character to the Keweenawan and Animikie series occur overlying the Laurentian in many parts of the Protaxis, not only along its margin, but as outliers at many places in the interior. It occurs extensively developed about the Arctic Ocean and about Hudson's Bay, and a large area of rocks referred to the same age also occur near the height of land about Lake Mistassini. "Throughout the whole of the vast northern part of the continent this characteristic Cambrian formation, composed largely of volcanic rocks, apparently occupies the same unconformable position with

[1] A. C. Lawson.—"Notes on the Pre-Palaeozoic surface of the Archean Terranes of Canada." Bulletin of the Geological Society of America. Vol. 1, 1890.

[2] "A Fragment of Primeval Europe." Nature, August 26, 1888.

regard to the underlying Laurentian and Huronian systems. Its present remnants serve to indicate the position of some of the earliest geological basins, which from the attitude of the rocks appear to have undergone comparatively little disturbance. Its extent entitles it to be recognized as one of the most important geological features of North America."[1] It would, therefore, seem that in Cambrian times a not inconsiderable part of the Archean Nucleus was under water. Outliers of Cambro-Silurian age are also found at several points lying well within the margin of the Nucleus, as for instance in the Ottawa River about Pembroke at a distance of fifty miles, and at Lake St. John at the head of the Saguenay River at a distance of one hundred and thirty miles from its present limit. There is reason to believe that a similar outlier exists in the interior of the northern part of the Peninsula of Labrador, so that the Lower Paleozoic sea must also have covered considerable areas in the eastern half of the Protaxis, where now nothing but Laurentian is to be seen. In that portion of the Protaxis lying to the west of Hudson's Bay strata of Cambro-Silurian and Devonian age extend up from the basin of Hudson's Bay on the east and from the great plains on the west far over the Laurentian Plateau and probably, according to Dr. Dawson, originally inosculated. Strata of Upper Silurian and Devonian age are not known to exist in the eastern half of the Protaxis, of which the typical Laurentian area forms part, with the exception of a small outlier of Niagara age on Lake Temiscamangue at the head waters of the Ottawa—neither do any other deposits of later age occur with the exception of the Glacial Drift. What evidence there is, therefore, would rather indicate that the area, during late Paleozoic, Mesozoic and earlier Tertiary times, was out of water. If so, it must have undergone during this great lapse of ages a process of deep seated decay and denudation, culminating in the extensive glaciation to which it was subjected in Pleistocene times.

During this latter period the whole area was exposed to

[1] G. M. DAWSON.—"Notes to accompany a geological map of the northern portion of the Dominion of Canada." Report of the Geological Survey of Canada, 1886. p. 9, R.

ice action, with the exception of the highest part of the Nucleus —the mountains of the Labrador coast—which, except toward the base, are still "softened, eroded and deeply decayed."[1] This extensive denudation served to remove all but mere remnants of any Paleozoic strata originally deposited on the Archean of this area, while the deep decay of the Archean rocks themselves would account for the immense numbers of gneiss bowlders in the drift, which in all probability are but smoothed cores of "bowlders of decomposition." That an immense amount of material was removed from the surface of the area during the glacial age is shown by the immense quantities of Archean material which occurs scattered over the surface of the Nucleus itself, as well as in the drift to the south. The glaciation, with the depression and uplift which succeeded it, was the last episode in the evolution of this "original" Laurentian area and one which impressed upon it its present surface characters and type of landscape.

It is now an immense uneven plateau, comparatively slightly accentuated except along the Labrador coast. The surface is covered with glaciated hills and bosses of rock with rounded, mammilated, flowing contours interspersed with drift covered flats and studded with thousands upon thousands of lakes great and small. A country which in the far north is often bleak and desolate, but to the south, where it is covered with luxuriant forest, is often of great beauty, especially when clothed with the brilliant foliage of autnmn. Even now, however, it is passing into a further stage of its history, the smooth or polished glaciated surfaces are becoming roughened by decay, the softer gneissic and limestone strata are again commencing to crumble into soil, and a new epoch has been inaugurated in which the marks of the ice age are being gradually effaced.

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[1] ROBERT BELL.—"Observations on the Geology etc., of the Labador Coast, Hudson's Strait and Bay." Report of the Geological Survey of Canada. 1882–3–4, p. 14, DD.

MELILITE-NEPHELINE-BASALT AND NEPHELINE-BASANITE FROM SOUTHERN TEXAS.

These basaltic rocks were collected by Professor Dumble and Mr. Taff, in Uvalde County, southern Texas. On the geological map of the United States, compiled by C. H. Hitchcock, 1886, there are two of the localities marked near the boundary of the Cretaceous and earlier Tertiary formation, between 99° and 100° longitude, and on the 29th degree of latitude. According to the statement of Professor Dumble, one part of the rocks appears in dikes in the upper portion of the lower Cretaceous formation, while the other forms hills and buttes. Upon microscopical examination it is evident that the specimens collected belong to two different groups of rocks. The microscope shows that those occurring in dikes consist of typical melilite-bearing nepheline-basalt, while those making up hills and buttes are nepheline-basanites tending toward phonolites in composition.

The melilite-nepheline-basalts have a typical basaltic appearance. In a dense black groundmass, the only phenocrysts seen by the naked eye are numerous olivines. Under the microscope there appear in addition to the olivine the following minerals: augite, nepheline, melilite, magnetite and perovskite. As to the proportion of nepheline and melilite, it can be said, that in nearly all the specimens examined, the two minerals are found in about the same amount. For this reason these rocks can be placed under the head of nepheline-basalt as well as under that of melilite-basalt, or they may be called melilite-nepheline-basalt. Only one of the specimens is entirely free from melilite. Feldspar is wholly wanting. All of the specimens are in a very fresh condition, and even the melilite shows only slight indications of decomposition. The specimen free from melilite corre-

sponds in structure and composition with the other specimens, except for the absence of melilite and perovskite, and so they may be described together.

All the rocks are porphyritic, since they bear large phenocrysts of olivine. Under the microscope the olivine is colorless and transparent, and only shows indications of serpentinization along the edges and fissures. It contains rounded inclusions of glass, abundant in some sections, besides octahedrons of magnetite, and others that are transparent with a brownish violet color. Whether the latter are a mineral of the spinel-group or belong to perovskite, with which they accord in color, could not be decided.

Augite occurs in only one generation; phenocrysts of augite are wanting. In the rather coarse-grained groundmass, it becomes the most abundant constituent. The mineral shows a grayish-brown color, common to basaltic augite, sometimes with a tint of violet. It generally forms well-shaped crystals, rarely irregular grains, and bears inclusions of magnetite and glass.

Melilite occurs in the groundmass in large and well-shaped crystals, its dimensions never becoming as small as those of many of the augite crystals. They may be designated as microporphyritical phenocrysts. Cross sections parallel to (001) reach a diameter of 0.5 mm. The shape of the melilite is the common one, tabular parallel to (001). The diameter of the tables generally exceeds their thickness from four to six times. Sections parallel to the prism-zone, therefore, are lath-shaped and the vertical axis lies perpendicular to their length; the axis of greatest elasticity coincides with the vertical axis. Between crossed nicols these sections show the particular blue interference colors characteristic of melilite and zoisite. Sections perpendicular to the prism-zone are eight-sided by reason of the planes (110) and (100), but frequently the outlines are rounded. In some of the sections examined the melilite incloses minute opaque grains arranged zonally, which present very sharply the prismatic outlines of their host. Besides the two prismatic faces above mentioned, there is also a ditetragonal prism, the angle of which upon the adjoining faces of (110) and (100) was found

to be nearly equal, 20°–22°. According to this measurement the prism must have approximately the position of (940); the angle of the latter upon (110) is 21° 2′, the angle upon (100) = 23° 58′. A particular phenomenon in the growth of the melilite is the fact that the base does not generally present an even plane, but shows a conical depression. The shape of the lath-shaped sections then resembles the profile of a biconcave lens. Sections parallel to the base are isotropic between crossed nicols and show, when they are not too thin, an indistinct dark cross in convergent light. The cleavage parallel to (001), the cross-fibration of the lath-shaped sections and the occurrence of the spear-shaped and peg-shaped inclusions arranged parallel to the *c* axis (the so-called *Pflockstruktur*) are very distinct. Inclusions of pyroxene, magnetite and glass are common; as already mentioned, these inclusions are generally arranged in zones. In sections parallel to (001) they fill the central parts of their host, and often make up two or three concentric zones. These sections closely resemble leucite because of their rounded shape, the arrangement of the inclusions and the lack of double refraction. Melilite becomes nearly colorless and transparent, but in comparing it with the white, colorless nepheline, it shows a feeble yellow tint. Decomposition has taken place to only a small extent; it begins along the cross-fibration, and greenish-yellow alteration-products result, the fibres of which are perpendicular to the length of the lath-shaped sections.

Nepheline is always fresh, colorless and transparent; it rarely exhibits a regular shape, but generally forms an aggregate of irregular grains, cementing the other components; it is evidently the latest formed mineral in the rock.

There is abundant magnetite besides perovskite, the common associate of melilite, which occurs in small octahedrons and irregular grains. The perovskite becomes transparent with a brownish-violet color, and shows in some sections a feeble, abnormal double refraction. There appears to be no isotropic base in the normal rock, but if any is present, it must be in a very small amount. There are coarser grained spots in the rock,

which are rich in a partly chloritized base, and in which nepheline occurs in well-shaped crystals.

The second group of rocks, as already mentioned, falls under the head of nepheline-basanite poor in olivine. And since the specimens bear sanidine phenocrysts beside plagioclase, it forms a transition to phonolite. The rock-specimens have a more andesitic than basaltic appearance. Numerous phenocrysts of hornblende and augite are imbedded in the dense bluish-gray groundmass. The next most abundant mineral is nepheline in the form of phenocrysts, in part well-shaped crystals, in part rounded, the largest of which are 0.5 cm. in diameter. The nepheline differs from the feldspar in having a grayish color and greasy lustre. Phenocryst of feldspar and crystals of olivine are scarce. Beside these components, the rocks contain apatite, some titanite and iron ores. Under the microscope olivine is seen to be scarce. It is fresh and shows the normal properties. It contains minute octahedrons of picotite and in some sections abundant inclusions of a liquid with moving bubbles.

The amphibole mineral is a typical basaltic hornblende. It becomes transparent with a dark reddish-brown color and exhibits a strong pleochroism according to the following scheme:

$\mathfrak{a}$, brownish yellow, $\mathfrak{b}$ and $\mathfrak{c}$ dark reddish brown. Absorption, $\mathfrak{c} > \mathfrak{b} > \mathfrak{a}$.

The angle of extinction was examined in sections cut approximately parallel to the clinopinacoid (010) and was determined to be very small. This fact and the dark reddish-brown color are in all probability due to a high amount of Fe_2O_3. The dependence of the angle of extinction upon the amount of Fe_2O_3 in minerals of the amphibole group has been recently established by Schneider and Belowsky. The basaltic hornblende shows the well-known dark borders produced by reabsorption by the magma in an early stage of consolidation. In many cases nothing of the original mineral is preserved; the whole hornblende is replaced by a fine grained aggregate of pyroxene and magnetite, presenting clearly the outlines of the absorbed mineral.

The group of pyroxenic minerals is represented by two mono-

clinic augites. One of them exhibits a violet-gray color in thin section and belongs to the basaltic augites; the other one becomes transparent with a dark green color. Both form numerous phenocrysts, but the first occurs somewhat more frequently. They occur as single crystals and are also grown together in a zonal manner, the green one always forming the center, the gray one the outer parts of the crystals. Hence the gray augite is the younger. The pyroxene in the groundmass shows the same color and properties. The pleochroism of the two minerals is as follows:

	Gray augite.	Green augite.
$\mathfrak{a}$	Brownish-yellow	Light yellowish-green
$\mathfrak{b}$	Violet-gray	Dark gray-green.
$\mathfrak{c}$	Violet-gray	Dark green.

The angle of extinction, c: $\mathfrak{c}$, is large and, as may be seen in the zonal crystals, it is somewhat larger in the gray pyroxene than in the green. The extinction in sections cut approximately parallel to (010) has been observed to be about 47 degrees (gray augite) and 41 degrees (green augite). The two pyroxenes show in addition to the cleavage parallel to (110) another but less distinct one parallel to (010). Inclusions of magnetite, apatite and glass are common.

Phenocrysts of feldspar are scarce. In part they show the polysynthetic twinning lamination of plagioclase; in part the latter is wanting and one of the latter feldspars, which was isolated and examined for specific gravity and optical properties, was found to be sanidine. Phenocrysts of nepheline are more frequent than those of feldspar. The mineral appears partly in the form of short-prismatic crystals, partly in rounded grains. It presents distinct cleavage, parallel to (1010) and to (0001), and the usually observed optical properties. Isolated grains are decomposed by hydrochloric acid with the separation of gelatinous silica; the resulting solution when evaporated gives numerous cubes of NaCl. Inclusions are scarce; there are fluid cavities with moving bubbles, generally arranged in rows, besides some pyroxene crystals.

Apatite forms short and stout crystals always filled with in-

clusions of liquids. The opaque ore grains, judging by their ready solubility, belong to magnetite. The groundmass of these rocks consists essentially of pyroxene in well-shaped prisms, lath-shaped feldspar, without twinning lamination or in single twins according to the Carlsbad law and nepheline. The feldspar of the groundmass in all probability is mostly sanidine. Nepheline is abundant and occurs in well-shaped crystals. Small patches of a colorless base occur between the crystalline components.

The structure of the rocks is hypocrystalline-porphyritic on account of the occurrence of an isotropic base and the repetition of the crystallization of pyroxene, nepheline and feldspar. Although the specimens by their whole habit and structure belong under the head of nepheline-basanite poor in olivine, the presence of sanidine as phenocrysts causes them to form a transition to the group of phonolites. Unfortunately, analyses of these rocks have not yet been made.

A microscopical examination of the basaltic rock from Pilot Knob, near Austin, Travis County, was made for the purpose of comparison with the rocks from southern Texas just described. The rock was found to be a nepheline-basalt porphyritic with numerous phenocrysts of olivine. The fine grained ground-mass consists essentially of augite-crystals cemented by non-individualized nepheline in very small amount.

A. OSANN.

SOME DYNAMIC PHENOMENA SHOWN BY THE BARABOO QUARTZITE RANGES OF CENTRAL WISCONSIN.

THE quartzite ranges of Baraboo extend east and west for about thirty miles, one lying north, and the other, the main range, lying south of the City of Baraboo. The geology of this district is admirably given by the late Professor Irving.[1] Not only is the general geology clearly described, but remarkably accurate descriptions are given of the character of the quartzite, and the phenomena shown by it, considering the fact that the report was written nearly twenty years since. The unconformity existing between the quartzite and the Cambrian was later more fully described.[2] The induration of the Baraboo quartzite has been explained as due to the enlargement of the original quartz grains; and to the deposition of independent interstitial quartz.[3] The present note is based upon recent observations on the East Bluff at Devil's Lake and on the exposures at the Upper Narrows of the Baraboo River.

The section across the ranges, as given by Irving, is shown by Fig. 1. The two ranges together, as thus represented, are less than the north half of a great anticline, the south side of the south range being near its crown. This structure involves a very great thickness of quartzite, and was offered with reservation by Professor Irving. He says: "The hypothesis is not altogether satisfactory. The entire disappearance of the other side of the great arch, as well as the peculiar ways in which the

[1] The Baraboo Quartzite Ranges, by R. D. Irving. In Vol. II, Geol. of Wis., pp. 504–519.

[2] The Classification of the Early Cambrian and pre-Cambrian Formations, R. D. Irving. In 7th Annual Rep., U. S. G. S., pp. 403–408.

[3] Enlargement of Quartz Fragments and Genesis of Quartzites, by R. D. Irving and C. R. Van Hise. In Bull. 8, U. S. G. S., pp. 33, 34.

ranges come together at their extremities are difficult to explain by it. It may be said in this connection that the dip observations toward the west are not so satisfactory or numerous as they might be." The question naturally arises whether or not the great width of the ranges in the central part of the area may not be partly explained by monoclinal faulting, and thus reduce the supposed thickness of the beds.

The layers of quartzite are ordinarily very heavy, but the changing character of the original sediment is such as to make it easy to follow the layers. Some beds were composed of fine

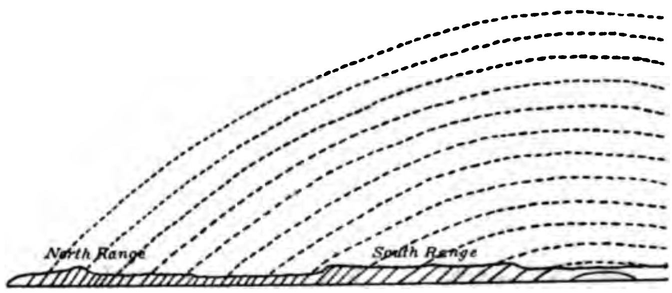


FIG. 1.—Ideal Sketch, showing structure and amount of erosion of the Barboo Ranges. After Irving.
Scale natural, 12,000 feet to the inch.

grains of quartz, mingled with clayey material, others of coarse grains with little clayey material, and others of pebbles so large as to pass into an unmistakable conglomerate. The pebbles of the conglomerate are mainly white quartz and red jasper. It is thus easy to discriminate the bedding of the series from the heavy jointing which occurs, cutting the bedding in various directions, and from a secondary cleavage and foliation which occurs in certain localities.

From the general work of many geologists on dynamic action in folding, it is to be expected that the amount of movement necessary for accommodation between beds, and consequently the dynamic metamorphism resulting from shearing, would be less near the crown of the anticline than on the leg of

the fold. That is, dynamic metamorphism ought not to be so extensive in the south range as in the north range. The facts described by Irving,[4] and those noted by me, fully agree with this anticipation. The central parts of the heavy, little inclined beds of the south range are largely indurated by simple enlargement. The pressure has not been sufficient to obliterate the cores, but has apparently granulated the exterior of some of the larger fragments, as in hand specimens the exteriors of the large blue quartz grains are white. Very generally the grains show slight wavy extinction. A few of them are distinctly cracked. The crevices thus formed and those in the interstices have been filled in large part by infiltrated silica, but their positions are plainly indicated by difference in extinction, by bubbles, by iron oxide, or by secondary mica which has taken advantage of the minute crevices.

However, as described by Irving, between the heavy beds of quartzites are often layers, cut by a diagonal cleavage which dies out in passing into the thick beds. The layers showing cleavage sometimes pass into those showing the beginning of foliation, the rock then nearing a schist. In the centers of the schist zones, the schistosity approaches parallelism with the bedding, and in passing outward curves from this direction until it crosses the bedding at an angle, at the same time becoming less marked and grading into ordinary cleavage, which dies out in the quartzite. Upon the opposite side the transition is of the same character, but the curve is in the opposite direction.

Irving apparently regarded these shear zones as originally beds of a different character from the adjacent quartzite, and his conclusion is fully borne out by the thin sections. The microscope shows that the grains of quartz are of small size, and separated to a greater or a less extent by interstitial clayey material. Because of this partial separation of the grains of quartz, they have not been granulated to the extent that one would expect from the schistosity of the rock, most of the original

[4] The Baraboo Quartzite Ranges, by R. D. Irving. In Vol. II, Geol. of Wis., pp. 510, 516.

cores being plainly visible. They, however, often show wavy extinction and even cracks, but not to a greater degree than the grains in the massive quartzite; for in the latter the full stress of the pressure has been borne by the grains in full touch, not separated by a plastic matrix, as are the grains of quartz in the argillaceous layers. In the matrix of the schist are numerous small flakes of muscovite, arranged with their longer axes in a common direction, much finely crystalline quartz, and a good deal of iron oxide.

It is concluded that the clayey character of the beds, and, consequently, the greater ease of movement within them, has located the slipping-planes and shear-zones, necessary in order to accommodate the beds to their new positions. On the south range, near Devil's Lake, these shear-zones are generally not more than six or eight inches wide. They may be well seen just back of the Cliff House, and on the Northwestern Railway, about one-half mile south of this house. All of these shear-zones are parallel with the bedding, and illustrate the possibility, so far as I know first mentioned by H. L. Smyth, that a crystalline schist, with schistosity parallel to bedding, may be produced by shearing along the bedding-planes.

On the railroad track, near the locality where these shear-zones may be seen, is also an almost vertical shear-zone, two to four feet wide. It therefore cuts almost directly across the beds of quartzite, which here incline to the south about twelve or thirteen degrees. Throughout this band, the quartzite is broken into angular trapezoidal fragments, the longer directions of which are vertical, and which may be picked out with the hammer. In certain parts of the zone well-defined gruss or friction clay, produced by the grinding of the fragments against one another, has been produced. This is clearly a plane of faulting. How much the throw of this fault is it is not easy to say, as the heavy beds of quartzite are so similar that it is impossible to certainly identify them. At this place there is, however, a change in the character of the quartzite, layers of light color being overlain by other beds, which are more heavily stained with iron oxide. This

same succession is seen on both sides of the fault, and if beds of like character correspond, the amount of the throw is twenty to thirty feet, and the south side has dropped relative to the north side. In other words, the faulting is in the right direction to reduce the theoretical thickness of the sediments as given by Irving. The district has not been closely examined for other faults, but the existence of one fault, even of a minor character, suggests that a careful study of the whole area with reference to faulting should be made, in order to determine what deductions may possibly be made from Irving's estimate of the probable thickness of the quartzite.

At the upper narrows of the Baraboo, near Ablemans, we are on the north leg of the anticline. The dip is throughout from seventy to ninety to the north, and in some places the layers are slightly overturned. The slipping along the bedding has here been much greater. While in this area there are heavy beds of quartzite which have not suffered great interior movement, other beds have been sheared throughout, being transformed macroscopically into a quartz-schist, but the foliation is strongly developed. In other places, as described by Irving,[1] where the rock is a purer quartzite, for a distance of 200 feet or more across the strike, the rocks have been shattered through and through, and re-cemented by vein quartz.

For the most part the rock is merely fractured, the quartz fragments roughly fitting one another, but there are all gradations from this phase to a belt about ten feet wide of true friction conglomerate, the fragments having been ground against one another until they have become well-rounded (a Reibungs breccia). Between the boulders of this zone is a matrix, composed mainly of smaller quartzite fragments. The whole has been re-cemented, so that now the mass is completely vitreous. This belt of friction conglomerate at first might not be discriminated from the Potsdam conglomerate, immediately adjacent, but a closer study shows how radically different they are. In

[1] The Baraboo Quartzite Ranges, by R. D. Irving. In Vol. II., Geol. of Wis., p. 516.

one the cementing material is vein-quartz; in the other the sandstone has been feebly cemented by quartz enlargement.

A movement later than the one which produced the cemented fractured rocks and breccia has broken broad zones of the massive beds of quartzite into lozenge-shaped blocks, the longer axes of which are parallel to the bedding and movement. These later-formed blocks have not been re-cemented by secondary quartz, and the cracks are taken advantage of in quarrying, the fragments being easily picked apart. Thus the rock has been affected by at least two dynamic movements, separated by a considerable interval of time.

The shear-zones, often several feet in width, particularly affect the more finely-laminated layers, which are lean in quartz, while the relief in the more massive layers has resulted in complex fracturing. In the first phase of production of the schist, the irregular fractures pass into rather regular fractures, cutting the beds nearly at right angles. As the action becomes more intense in the more argillaceous beds, the angle of fracture, or cleavage, as it may now fairly be called, becomes more acute, and in the most intense phase this cleaved rock passes into a well-developed schist, the foilation of which is parallel to the bedding. The phenomena of shearing are here therefore very similar to those at Devil's Lake, except that the process has gone farther.

When studied in thin section, the massive beds of quartzite show more decided effects of dynamic action than at Devil's Lake. However, the major portions of the grains of quartz have distinct cores which are often beautifully enlarged. In some cases nearly every grain has thus grown, perfectly indurating the rock. But, also, nearly every grain of quartz has a wavy extinction, and many of them have been fractured, as mentioned of a few of the quartz grains of the quartzites of the south range. In one case the pressure has been so great as to produce rather numerous roughly parallel lines of fracture. It is thus seen that the dynamic effects are not confined to the schist zones, but are also prominent within the heavy beds of quartzite. This was to

be expected; for while the major part of the accommodation necessary to bend the rock mass as a whole took place along the shear zones, the accommodation required to bend each of the rigid heavy beds of quartzite must have taken place within each layer. To the consequent intense pressure and the rubbing of the grains over one another, are wholly attributed their wavy extinction and fractures.

In the schists of the shear zones, as at the south range, the thin sections show that the original quartz grains were small; interstitial material was present, and mica has developed more largely than in the quartzite. However, in the most crystalline phases, the fragmental cores of the quartz grains and their frequent enlargements are plainly seen. Thus the shearing has not been sufficient to produce a completely crystalline schist, although this would not be macroscopically discovered, unless it were suspected because the rock is not thinly foliated.

As the dip of the quartzite is so steep at this locality, it is difficult to say how far the shifting of the beds over one another lessens the apparent thickness. The shear zones as well as the friction conglomerates appear to be parallel to the bedding. If they are exactly so, this shearing action would necessitate an estimate of the original thickness greater than now shown, since the shear zones probably have less width at the present time than the beds from which they were originally produced.

Cutting the bedding are heavy joints inclined to the north at an angle of 20° to 30°. If slipping had occurred along these in the right direction, this might cause a small thickness of beds to have a great apparent thickness. However, the schists above described weather out on the face of the cliffs, and are therefore marked by recessions in the walls. If slipping parallel to the jointing had occurred since the schists were formed, these depressions ought not to match on opposite sides of the joints; but, on the contrary, they continue unbroken from foot to top, and probably the joints were formed simultaneously with or later

than the belts of schist. Consequently, at the upper narrows of the Baraboo no evidence was found of faulting which could reduce the estimated thickness of the quartzite as given by Irving.

As Irving clearly saw, bearing strongly in favor of the theory of a great fold, is the increasing steeper dip of the layers in passing north. The phenomena of movement and metamorphism corresponding so exactly to those required by a simple fold, the question may be asked if these are not evidence of some weight in favor of the general correctness of Irving's conclusion as to the structure. Had monoclinal faulting extensively occurred, it would not have been necessary to have had so great a readjustment of the beds as has been shown to occur by the schists, cleavage, and the exceedingly intricate macro-fracturing and micro-fracturing of the rock beds and their constituent particles.

In addition to the phenomena described by Irving, in summary, the Baraboo quartzite ranges show results of dynamic metamorphism as follows: A fine example of the Reibungs Breccia may be seen. A fault zone of limited throw exists. All phases are exhibited, between a massive quartzite, showing macroscopically little evidence of interior movement through a rock exhibiting in turn fracture and cleavage, to a rock which macroscopically is apparently a crystalline schist. The foliation of the schists is parallel to the original stratification, being consequent upon the movements of the beds over one another, readjustments occurring mainly in the softer layers. In thin sections the schists still give clear evidence of their fragmental origin, but also show the mechanical effects of interior movement. These same effects are apparent within the heavy beds of quartzite, some readjustment of the particles to their new positions being here also necessary. There is no evidence that the semi-crystalline character of the schist and quartzite are due to high heat. Nowhere are the particles fused. So far as they are destroyed it is by fracture, and the rock is again healed by cementation.

The rock, in its most altered condition being a semi-crystalline schist, and in other parts showing less change, can be connected with its original state. Had the folding been more intense, it is reasonable to suppose that the entire rock would have been transformed into a completely crystalline quartz-schist, showing no evidence of clastic origin, and possibly the foliation throughout would have corresponded to the original bedding.

C. R. VAN HISE.

THE CHEMICAL RELATION OF IRON AND MANGANESE IN SEDIMENTARY ROCKS.

IRON and manganese are frequent constituents of sedimentary rocks, in some places occurring finely disseminated through sandstones and shales, or forming a part of limestones, in other places forming the mass of the deposit in which they occur. They are both derived primarily from similar, and often from the same sources, and are in many respects alike in their chemical behavior in nature. For these reasons it is to be expected that they would frequently, if not generally, be deposited in intimate association. Such is found to be the case, and iron and manganese are often closely associated in the same deposits. Very often, however, iron and manganese deposits occur close together, but distinctly separated, while sometimes extensive deposits of iron, and less commonly of manganese, occur with little or almost no association with each other.

It is the object of the present paper to discuss the agencies which are instrumental in causing these substances to be deposited sometimes together and at other times separately. The subject is of interest as showing how slight differences in the chemical behavior of their salts may cause the almost complete separation of metals once intimately associated.

THE CONNECTION OF IRON AND MANGANESE IN NATURE.

A few words concerning the relation of manganese to iron in nature will perhaps make the following discussion clearer. One of the most common modes of occurrence of manganese is with iron, though extensive deposits containing manganese more or less free from iron often occur. When associated with iron, manganese occurs with it in various ways. Sometimes the two are intimately mixed, so that they have the appearance of a homoge-

neous mass, resembling iron ore when iron is in the preponderance and manganese ore when manganese predominates. In such cases there appears to be no tendency to combine in one fixed proportion, though, as iron is a much more abundant substance than manganese, the mixture most commonly contains an excess of iron, and exists in the form of a manganiferous iron ore. The manganese, when not intimately mixed with the iron, may occur in it in pockets or as scattered nodules and concretions. Such occurrences as those described are frequent in the Lake Superior iron region, the Appalachian Valley of the eastern states, in Nova Scotia, Arkansas, Colorado, New Mexico and innumerable other places. In Virginia very common occurrences are alternating layers of iron and manganese ore. The iron in such cases is generally in the larger quantities and the more continuous deposits; while the manganese is often represented by thin lenticular layers or by bands of nodules.

From such cases, where iron predominates, there are all gradations in admixture, up to the rarer cases where manganese predominates. Frequently a given geologic horizon is characterized by both iron and manganese, though in one case it may contain only iron, in another only manganese, and in still another iron and manganese mixed in various proportions. A remarkable case of this is seen in the iron and manganese horizons immediately above, or a short distance above, the Paleozoic quartzite, on the east side of the Appalachian Valley, especially in the Valley of Virginia.[1] Here deposits of iron ore, of manganese ore, and of both ores mixed, are found at various points along the same geologic horizons. Similar alternations also occur in the Lower Silurian novaculites of the Ouachita Mountains of Arkansas,[2] in Cebolla Valley, in Gunnison county, Colorado,[3] and in

[1] The exact age of the iron and manganese deposits here referred to is, in some cases, a little uncertain. Some may be Cambrian, others Silurian, but the exact determination of the age of the horizon is not a part of the present discussion. The matter has been discussed by the writer in Geological Survey of Arkansas, 1890, Vol. I., pp. 376–379.

[2] See Geological Survey of Arkansas, 1890, Vol. I., pp. 320–325.

[3] See Geological Survey of Arkansas, 1890, Vol. I., pp. 456–457.

many other places. In many cases certain horizons are characterized over large areas by iron alone, and but little manganese, as is well seen in the Clinton formation and in the Tertiary iron-ore horizons of Arkansas and Texas; while, on the other hand, some areas of certain horizons contain considerable quantities of manganese and very little iron, as is seen in parts of the Marine limestone in New Brunswick and Nova Scotia, and also in parts of the metamorphosed Cretaceous shales of California.

THE SOURCE OF IRON AND MANGANESE IN SEDIMENTARY ROCKS.

The iron and manganese contained in sedimentary strata may be considered as derived primarily from the decay of pre-existing rocks. Some of the later sedimentary rocks may have derived a part or all of their iron from older sedimentary rocks, which, in turn, had derived their iron and manganese from still older rocks. In this way the iron and manganese in a given geologic horizon may have formed a part of various older horizons before they reached their present resting place, but, in every case, their primary source can be traced back to the original materials from which sedimentary rocks were first formed. In certain cases the sea water has supplied a certain amount of iron and manganese to sedimentary rocks, but in such cases the sea water acts only as a carrier of these materials from the land areas or from submarine sources to the strata then forming.

THE TRANSPORTATION OF IRON AND MANGANESE IN NATURE.

The process that goes on in this interchange of iron and manganese from older to younger rocks is as follows:

(1) The conversion, by surface agencies, of the minerals containing iron and manganese into forms that can be taken into solution by surface waters.

(2) The solution of the iron and manganese in surface waters, acidulated with organic and sometimes inorganic acids, and their transportation in this form from the areas of older rocks to areas over which younger rocks are being deposited.

(3) Finally, the precipitation in one or more of several ways of the iron and manganese contained in solution.

The iron and manganese thus chemically precipitated may be deposited either with mechanical sediments, such as sand, clay etc., or without them. If the deposition of mechanical sediments is largely in excess of the precipitation of iron and manganese, the final products will be beds of ferruginous shale, sandstone, etc., common in many geologic horizons. If the precipitation of iron and manganese is in excess of the deposition of mechanical sediments, the resulting products are deposits of more or less pure iron and manganese ore. Between these two extremes there are all gradations in the admixture of the iron and manganese with mechanical sediments.

Frequently the iron and manganese which were originally finely disseminated through shale, sandstone, etc., are subsequently concentrated into bodies of comparatively pure ore, and very commonly this concentration takes place by a process of re-solution of the iron and manganese and re-deposition by replacement with limestone, or, more rarely, with some other material. The limestone or other material which thus acts as a precipitant is often in the same series of strata from which the iron and manganese were removed, and thus these two substances, which were once in a finely disseminated condition, may be converted into deposits of comparatively pure ore and yet remain in the same general series of strata in which they were originally deposited. A remarkable case of this is seen in the iron deposits of the Penokee series in Michigan and Wisconsin,[1] to be mentioned again on page 370. It has also been suggested by H. D. Rogers[2] that certain siderite deposits in the Coal Measures were formed by the conversion of finely disseminated sesquioxide of iron into carbonate of iron by organic matter, and the subsequent segregation of the carbonate as now found in layers and nodules.

The surface waters that carry the iron and manganese to the strata being deposited at a given time are sometimes derived

[1] R. D. Irving and C. R. Van Hise, U. S. Geol. Survey, Tenth Ann. Report, 1888-1889, Vol. I, pp. 409-422.

[2] Geol. Survey of Penn., Vol. II, 1858, p. 739.

from areas in which iron predominates, sometimes from areas in which iron and manganese are both abundant, and sometimes, though rarely, on account of the scarcity of such regions, from areas in which manganese largely predominates over iron. If iron and manganese were always precipitated from these waters in similar chemical forms and under the same conditions, it would be expected that the strata deriving their iron and manganese from surface waters would contain those substances in the same relative proportions as they had existed in the rocks from which they were derived, and that they would be in an intimately mixed condition. Such is doubtless often the case, or at least approximately so; but it is also often the case that iron and manganese occur in separate deposits, yet in close proximity to each other and often alternating along the same horizon. Besides this, the two substances frequently form parts of the same deposit and yet are distinctly separate from each other. In such cases the question arises as to why the iron and manganese are not intimately mixed in the form of a manganiferous iron ore, as would be expected if they had been precipitated together. Moreover, deposits sometimes occur which are composed largely of manganese ore, with little or almost no iron, and when the source of the manganese is looked for, we often find that the rocks which probably supplied it contained both manganese and iron, and that the iron was present in a much larger proportion as regards the manganese than in the new deposit. Here again the question arises as to why the iron and manganese are not in the same relative proportions in the new deposit as they were in the rocks from which they were derived.

Four principal causes suggest themselves in explanation of this separation:

(1) It might be supposed that the deposits containing mostly iron and those containing mostly manganese received these constituents from waters derived from different sources, and carrying iron and manganese only in the proportions in which they deposited them. Under some conditions this explanation might suffice, but in many cases, such as when iron and manganese alternate

along the same geologic horizon, and yet in close proximity with each other, the explanation is entirely inadequate, for the deposits are too close to each other to have been formed from different supplies of surface waters.

(2) It might be supposed that the iron or the manganese had been leached out of a deposit of the mixed ores, leaving one free from the other and depositing the dissolved ore somewhere else. This explanation, except in special cases, also appears inadequate, because the reagents in surface waters, which dissolve iron and manganese, seem to affect both about equally, so that if one were dissolved, the other should be taken up in the same way. Doubtless small differences could be found in the behavior of the organic and inorganic compounds in surface waters towards iron and manganese minerals, but they would be small as compared with the more active reactions which go on.

(3) It might be supposed that a separation could be produced by secondary concentration such as segregation, replacement, etc. This has doubtless sometimes been the case, but where the concentrating action is not assisted by a difference in the chemical behavior of the two substances, the separation would only be on a small scale. Even in the case of concentration by replacement of limestone, if iron and manganese both acted in the same way during the replacement, it would be expected to find them deposited in an intimate mixture. Though this secondary concentration, therefore, unassisted by other agencies, would not produce all the results found in nature, yet, when it is thus assisted, it often plays an important part.

(4) The fourth, and what seems the most important, factor in the separation of iron and manganese, is that, though very often they are precipitated in the same form from the same solution, yet sometimes they are precipitated in different forms; and even when precipitated in the same form, the precipitation of one sometimes requires different conditions from the precipitation of the other. This fact will explain the alternate association and separation of iron and manganese, not only when no secondary concentration has gone on, but also in cases where

such concentration has taken place, such as in the replacement of limestone, etc.

It will now be attempted to show how the various degrees of association and separation of iron and manganese found in nature may be produced by different conditions during deposition.

THE FORMS OF IRON AND MANGANESE DEPOSITED AT ORDINARY TEMPERATURES.

The mineralogical forms in which iron and manganese are deposited from solution in nature at ordinary temperatures depend on the conditions of air and water, whether of an oxidizing or a reducing nature, and on the character of the associated organic and inorganic matter either in solution or on the floor of the sea, lagoon or bog in which the deposition occurs.[1] There are four principal methods by which iron and manganese are precipitated in nature from surface waters :

(1) By oxidation, as in the case of the precipitation of hydrous oxides and in the precipitation of the carbonate by the partial oxidation of more complex organic salts.[2]

(2) By reduction, as in the precipitation of sulphide of iron by the reduction of sulphate of iron.

(3) By gaseous or soluble precipitants, as in the precipitation of sulphide of iron by the action of sulphuretted hydrogen or a soluble sulphide on a soluble salt of iron, and as in other cases to be mentioned later.

(4) By replacement of carbonate of lime or some other substance. Different forms are precipitated by these different methods.

Iron at ordinary temperatures is usually deposited from solu-

[1] The solutions may be precipitated, as already shown, either with or without admixture with mechanical sediments; and there are in nature all gradations from almost pure deposits of iron and manganese ore to beds of shale, sandstone, etc. stained with iron or manganese. Subsequent concentration frequently causes decided changes in the latter deposits (see p. 370).

[2] It has been suggested by A. A. Julien (Proceed. Amer. Assoc. Adv. Sci., Vol. XXVIII., 1879, p. 356) that in some cases the carbonates of iron and manganese may be only the fixed residue of organic compounds of more complex form once in solution in surface waters.

tion as the hydrous sesquioxide, the carbonate, the sulphide or the hydrous silicate of iron and potash known as glauconite. Manganese under similar conditions is deposited as the hydrous oxide[1] or as the carbonate, and possibly sometimes, though very rarely, as sulphide.

When solutions of organic or inorganic salts of iron and manganese are freely exposed to the action of air, as in shallow or rapidly moving streams, or in lakes and some bogs, they are quickly oxidized and both may be deposited as more or less hydrous oxides. In many bogs, however, the metals may be precipitated as hydrous oxide on the surface where oxidizing agencies predominate, but when these oxides sink and come into contact with decaying organic matter, free from the active oxidizing influences of the air, they may be reduced to carbonates.

The carbonates of iron and manganese may be precipitated when the solutions containing them are protected from oxidation by a reducing agent, such as decaying organic matter, or by being far removed from the air. Carbonate of manganese, however, is a much more stable compound than carbonate of iron, and the oxidizing conditions are often sufficiently strong to cause the deposition of iron as hydrous sesquioxide and not strong enough to change the manganese from its carbonate form. It is not uncommon, therefore, to have iron deposited in one place as hydrous sesquioxide, and manganese carried further on and deposited as carbonate, or even under special conditions deposited as carbonate with the hydrous sesquioxide of iron. Fresenius[2] has shown that the warm springs of Wiesbaden, which contain iron and manganese among their other mineral constituents, deposit iron in the form of hydrous sesquioxide, while manganese is carried on further in solution and deposited as carbonate. In this behavior, therefore, we have the first striking difference in the deposition of iron and manganese, and it will be further discussed later on.

[1] This oxide is generally in the form of the peroxide or the sesquioxide in a more or less hydrous condition.

[2] Jahrb. des Vereins f. Naturkunde in Herz. Nassau, Vol. VI., p. 160 (Bischof).

The sulphides of iron and manganese differ very much in their nature and mode of occurrence. Iron is frequently deposited as sulphide, but manganese rarely occurs in that form, and when it does it is always in very small quantities. Iron forms several sulphides in nature: pyrite (FeS_2), marcasite (FeS_2),[1] pyrrhotite ($Fe_{11}S_{12}$), troilite (FeS) and numerous other more complex compounds unnecessary to enumerate here. Pyrite is the commonest form of iron sulphide, and occurs in rocks of all ages, from Archean to Recent. It is formed in nature by the action of soluble sulphides or sulphuretted hydrogen on soluble salts of iron, and also by the reduction of sulphate of iron by organic matter or other reducing agents. Manganese forms two[2] sulphides, alabandite (MnS) and hauerite (MnS_2). Both minerals are very rare, and so unstable that they rapidly oxidize on exposure. Alabandite is the less rare form, and usually occurs as a subordinate constituent of certain metalliferous veins or allied deposits.

Though the sulphides of manganese are easily oxidized, they are not so unstable that, had they ever been formed in considerable quantities in sedimentary deposits, they would, even at considerable depths, have left no trace of their former presence. Moreover, the sulphide of manganese, as produced artificially,[3] is soluble in certain organic acids, notably acetic, and, as the conditions for the deposition of sulphides of metals in sedimentary deposits generally require the presence of organic matter, it is not improbable that some of the acids given off by such matter would be capable of dissolving sulphide of manganese. Here, then, is one reason why manganese might not be deposited as sulphide under some conditions which would cause the precipitation of sulphide of iron. Moreover, the artificial formation of sulphide of manganese (alabandite) in the laboratory is brought

[1] Marcasite has the same composition as pyrite, but differs in crystalline form.

[2] Manganese also occurs in the mineral youngite, which contains lead, zinc, iron, manganese and sulphur, but the mineral is considered of doubtful homogeneity. (See System of Mineralogy, E. S. Dana, 1892).

[3] When manganese is precipitated artificially as sulphide it is usually in the form of the monosulphide (MnS), in either a hydrous or an anhydrous form.

about most easily at high temperatures. It has also been noted that when manganese, in the form of the alloys spiegeleisen and ferro-manganese, is added to molten steel, it bodily removes a part of the sulphur; and it is thought by some metallurgists, that sulphide of manganese is formed and carried into the slag.

These and other indications of the more easy transition of manganese into the form of sulphide at high rather than at low temperatures afford another cause which might prevent sulphide of manganese from being formed in sedimentary deposits, for such deposits are usually laid down at ordinary temperatures. On the other hand, they also afford a cause which might lead to the deposition of the sulphide of manganese in certain metalliferous veins and other deposits, where the temperature at the time of deposition may have been high.

In many of the silver and lead deposits of the Rocky Mountains manganese oxides occur with the superficial oxidation products of the sulphides of other metals, and it has often been suggested that the manganese also was originally in the form of sulphide. This may be true in some cases, for alabandite has been found in a few metalliferous deposits in Colorado, Mexico, Germany, Peru and elsewhere, but in most cases, at least in the Rocky Mountains, when the level is reached at which the oxidized forms of lead, zinc, iron and other metals pass into sulphides, the manganese passes into carbonate or silicate, and remains in one or both of those forms to all depths that have been reached.

In the deposition of iron and manganese as sulphide, therefore, there is a most marked difference of behavior, and here again is a good cause for the separation of the two substances in sedimentary rocks, as will be more fully explained below.

Iron is often deposited in sedimentary formations as the hydrous silicate of iron and potash known as glauconite, and composes the mass of the large greensand beds common in Cretaceous and Tertiary strata; but manganese is not found in an exactly similar condition.[1] Here again, therefore, is an import-

[1] Manganese occurs in various hydro-silicates, but they do not appear to be deposited as sedimentary strata in the same manner as glauconite.

ant difference in the modes of deposition of iron and manganese, which also will be mentioned again.

It will thus be seen that while some of the forms in which iron and manganese are deposited are the same, others differ very widely, and even similar forms are often deposited under different conditions. It is doubtless to these various forms and conditions of deposition that the alternate association and separation of iron and manganese in nature are due.

CAUSES OF THE ASSOCIATION OF IRON AND MANGANESE.

The very frequent intimate association of iron and manganese in sedimentary rocks is what would be expected from a deposition as oxide or carbonate in basins such as coastal lagoons or bogs, where the waters moved very slowly, or not at all, for under such conditions, they are often deposited together.[1] Moreover, it is a well-known fact that isomorphous substances have a strong tendency to combine in a homogeneous mass, and to crystallize together in different proportions. Carbonate of iron and of manganese are isomorphous with each other, and this is hence a possible cause of the frequent intimacy of their association, such as is seen in almost all manganiferous spathic iron ores, whether these ores are formed by direct precipitation or by replacement of carbonate of lime. The oxidation of such a mixture would give the common form of an intimately combined iron and manganese ore.

Since there is usually more iron than manganese in the rocks from which both metals were originally derived, the surface waters draining from areas of such rocks usually contain the metals in a similar proportion. Hence, in cases where the deposition of the carbonates of both occurs at the same spot, the isomorphous carbonates derived from the solutions have a larger percentage of carbonate of iron than of carbonate of manganese, and the resulting oxides contain the two metals in the same

[1] If the water moved very slowly, the deposition would probably take place approximately in the same spot; if the waters moved more rapidly, the iron might be deposited in one place and the carbonate in another, in the way explained on page 363.

proportion, thus giving rise to the common low-manganese iron ores.

The hydrous oxides of iron and manganese, however, are not isomorphous,[1] and, therefore, when they are precipitated together, as in bog-deposits, the association is often much less intimate than in the cases just mentioned, and is simply due to the fact that, under certain conditions, the oxides of both metals are precipitated in the same place.

CAUSES OF THE SEPARATION OF IRON AND MANGANESE.

When iron and manganese ores occur in more or less separate deposits, it becomes necessary to suppose the action of influences different from those which cause the deposition of both together, and such influences are to be found in the different modes of precipitation, under certain conditions, of the two metals. It has been shown by Fresenius[2] that certain warm springs, on reaching the surface, first deposit hydrous sesquioxide of iron, and farther on carbonate of manganese. This not only points to the well-known fact that carbonate of iron is more easily oxidized than carbonate of manganese, but it also leads to the belief that the bicarbonate or other salt of iron in the water is more easily oxidized than the manganese salt.

An action somewhat similar to that described by Fresenius readily explains the occurrence of manganese sometimes in entirely separate deposits, sometimes in distinct but closely alternating deposits.[3] Under certain conditions, if the waters from which the precipitation took place were moving, the iron and manganese, owing to the difference in oxidability, as stated above, would be laid down in different places, resulting in the formation of deposits of iron ore free from manganese, and manganese ore free from iron in different positions along the plane of the same geologic horizon. Such occurrences are often seen in the iron

[1] The hydrous oxides of iron are not crystalline. [2] See p. 363.

[3] Bischof suggests that the action described by Fresenius causes the separate deposition of iron and manganese; and also that it explains the occurrence of large deposits of manganese ore in regions where the iron ore contains least of that ingredient. (See Elements of Chemistry and Phys. Geol., Vol. III., pp. 531–532.)

regions of the Appalachian Valley, where there are often found, in different places along the same belt, deposits of iron ore and deposits of manganese ore in positions similar with relation to the enclosing rocks.

These conditions of moving water might also cause the occurrence of the two ores in interstratified layers, as is sometimes the case. Such a condition would result if iron were deposited in a certain place at one time, and if, later, on account of some increased facility for oxidation, iron was deposited before it reached that place, and the manganese, being less easily precipitated, were carried on and laid down upon the first deposit of iron.

Suppose the metalliferous solutions to be confined in a shallow basin, or, at least, to pass through it so slowly that they become thoroughly oxidized. Under such conditions the deposition of iron and manganese would go on continuously, and so nearly on the same spot that a comparatively homogeneous manganiferous iron ore would be formed. If the supply of metalliferous solutions were not continuous, but were intermittent, as is sometimes the case in local basins, such as coastal lagoons, which are often dependent for their supply of water on the changes of season and the sudden fluctuations of weather, then interstratified layers of iron and manganese ore might be produced. The iron, becoming oxidized on the surface, sinks to the bottom, possibly in some cases to be converted there to the simple carbonate by organic matter. Further oxidation precipitates hydrous oxide or carbonate of manganese on top of the iron. A renewed supply of surface waters brings more solutions of iron and manganese, or else the evaporation of the water in the closed basin concentrates the materials which have not yet been precipitated. In either case there is a further alternate deposition of the two ores.[1]

Another process of separation of iron and manganese in nature might take place by the formation of sulphide of iron. It has already been shown that iron is sometimes deposited as sulphide and later oxidized in the same manner as the carbonate.

[1] In some cases these iron and manganese deposits are undoubtedly formed by the replacement of limestone or other rocks, as is further discussed on pages — to —.

Manganese, on the other hand, is rarely found as sulphide, and there is reason to think that the sulphide never represented the original form of any large sedimentary deposits of manganese ore (see pages 364 to 365). It seems probable, therefore, that from a solution of iron and manganese in surface waters the iron might, where the conditions are favorable, be precipitated as sulphide (FeS_2) and the manganese might be carried on in solution to be deposited somewhere else as oxide or carbonate. Subsequently the oxidation of the ores would give rise to oxide of iron from the sulphide and oxide of manganese from the carbonate; and the two ores, though occurring at the same horizon, would be separated by a greater or less distance.

After the deposition of the sulphide of iron, the conditions might change and permit the deposition, in the same place, of the carbonates of iron and manganese together. This is an easy case to imagine, and where such a deposit was exposed to surface influences, the resulting product would be oxide of iron from the underlying sulphide and a manganiferous iron oxide from the overlying isomorphous carbonates. Hence another possible cause of the frequent association of pure iron ores and manganiferous iron ores. It is possible also that after the solution of iron and manganese had been freed from the former by precipitation as sulphide, the manganese might be carried on and laid down as carbonate on a previous deposit of iron sulphide, and when such a combination was oxidized, the result would be oxide of iron and oxide of manganese in beds closely associated but yet distinct.

By supposing the iron sometimes to be deposited in sea water as glauconite, a manner in which manganese is not laid down (see page 365), a further means of separation of the two metals would result.

Thus by alternating the conditions of the deposition of iron and manganese in different forms, a great variety of methods of association and separation of the two metals can be produced.

The above discussion refers not only to the deposits of iron and manganese ores of notable size, but also to the iron and man-

ganese frequently found disseminated through shales, sandstones etc. In these rocks they usually form a small but often a very important part, for in many cases the iron and manganese is taken into solution from the rocks and redeposited by a process of replacement with carbonate of lime in neighboring beds of limestone, or more rarely by replacement with other rocks, thus giving rise to important ore deposits. The question of the association and separation of the iron and manganese in these replacement deposits depends on a number of conditions, the principal of which are, just as in the class of deposits that has been discussed, the conditions during deposition and the forms in which the iron and manganese are precipitated. The processes by which association and separation occur in replacement deposits differ somewhat in detail from the processes just discussed, but are based on the same principles.

Many of the iron and manganese deposits of the Appalachian region are supposed by many to be replacement deposits.. N. S. Shaler[1] in 1877 suggested that some of the iron deposits of Kentucky and Ohio were formed by the solution of iron from certain rocks, and its deposition in the form of carbonates by replacement with underlying limestone. Subsequently it was changed by oxidation to brown hematite. A notable case of replacement has also been shown by R. D. Irving and C. R. Van Hise[2] in the iron deposits of the Penokee series of Michigan and Wisconsin. Here the ore is supposed to be partly a replacement of chert in a trough between quartzite and igneous rocks. The solution that contained the iron was derived from strata in the same series of rocks in which the iron was re-deposited and contained a certain amount of manganese. It is shown how the iron and manganese were more or less separated in the replacement process and that the separation was due to the difference in the oxidability of the carbonates as explained on page 363.

R. A. F. PENROSE, JR.

[1] Kentucky Geol. Survey, Report of Progress, Vol. III., New Series, 1877, p. 164.

[2] U. S. Geol. Survey, Tenth Annual Report, 1888-1889, Vol. I., pp. 409-422.

SOME RIVERS OF CONNECTICUT.[1]

Outline.— Introduction.— Topography of Connecticut: The upland plateau, its origin, date, elevation, valleys sunk beneath its surface.— Lowland on the Triassic area. — Later oscillations.—Résumé of the topography.—Early drainage.—Re-adjusted streams.— Revived streams.— Unconformable rivers, consequent or superimposed.— Pleistocene changes; the Farmington, Quinnipiac, Scantic.— Abandoned gaps.

Introduction. In order to study intelligently the history of a river, one must first become acquainted with the present physical geography of the region in which the river lies, and know the stages of its development. Therefore, before classifying the rivers of Connecticut, I shall consider the topography of the state, and in a few paragraphs outline the successive cycles in the history of its growth. The scope of this article will not permit a discussion or even a full statement of the evidence on which these conclusions are based. They have been stated at considerable length by Professor W. M. Davis,[2] and the reader is referred to his papers for the complete discussion. His conclusions in respect to the physical geography are accepted here without question, and form the basis for the discussion on the rivers of the state.

Topography of Connecticut. Connecticut can be said to consist of two great areas quite distinct in topography and geologic structure.[3] On the east and on the west are the crystalline uplands which rise from sea level along the Sound to 1,700 and 1,800 feet in the northwestern part of the state, and to 600 and 700 feet in the northeastern. These uplands consist chiefly

[1] The author desires to express his obligation to Professor W. M. Davis for aid in the preparation of this article. It was first written under his direction and with the help of his suggestions when the author was in the graduate school of Harvard University. Prof. Davis is not responsible, however, for the statement of the views herein advanced, although in general it is believed that he is in accord with them.

[2] Amer. Jour. Sci. 3d ser., vol. xxxvii, 1889, p. 423. Bull. Geol. Soc. Amer., vol. ii, p. 545.

of gneiss and granite, probably of pre-Paleozoic age, which are now much folded, faulted and crumpled. Between these two areas of crystallines is a lowland belt of Triassic sandstone and shale, twenty to twenty-five miles wide, extending from New Haven north through the center of the state and including in its

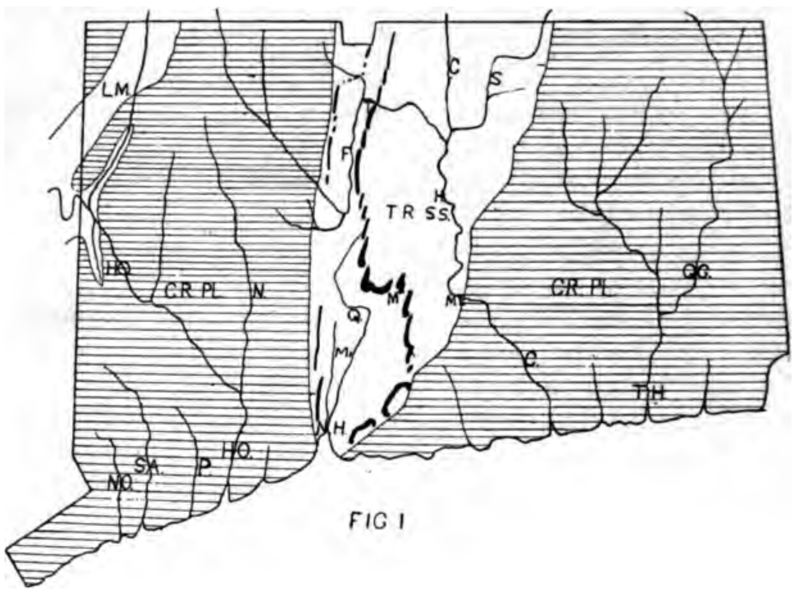


FIG I

[3] The rough diagrams accompanying this paper may aid the reader who is unacquainted with the details of the region under discussion. The abbreviations on the above figure are as follows: C. The Connecticut. Cr. Pl. Crystalline plateau (the shaded area). F. The Farmington. H. Hartford. Ho. The Housatonic. Lm. Limestone area. M. Meriden. Mi. Mill River. Mt. Middletown. N. The Naugatuck. N. H. New Haven. No. The Norwalk. Q. The Quinnipiac. Qg. The Quinnebaug. S. The Scantic. Sa. The Saugatuck. T. Tariffville. Th. The Thames. The unshaded area is the Triassic sandstone lowland, and the blackened areas represent the ridges of the faulted trap sheets.

borders New Haven, Meriden, Hartford, New Britain and many towns of lesser note. These sandstones form a monocline with an eastward dip of 10° to 30°, and in addition to being tilted they have been faulted since their deposition in a shallow, slowly-subsiding trough of crystallines. Their thickness is variously estimated—3,000 to 5,000 feet, Dana; 10,000 or more, Davis.

This lowland is interrupted by a series of trap ridges, which in general present steep faces toward the west, whereas their eastward slope is gradual, less than the dip of the sandstones.

The upland plateau. Suppose we ascend the highest point of these trap ridges, the old tower on Talcott Mt., nine miles west of Hartford; we are 900 feet above the sea level and more than 600 above the plain at our feet. A few miles to the west across the sandstone valley, rise the crystalline uplands, which extend far to the north and to the south. On the east across the Connecticut we see the eastern uplands. The first impression, which comes to one as he gazes upon these uplands and which is strengthened with each view, is that few hills rise above the general level of the plateau; the crest line is nearly horizontal, declining gently to Long Island Sound. Above this general level are a few rounded domes, but no sharp, towering peaks. Below it valleys have been cut, but they do not destroy the plateau-like appearance. A view from the western plateau across the sandstone valley shows the remarkably even crest line of the trap ridges, a crest line which approximates in height the uplands on the east and west. A nearer view of the upland corroborates our first impressions of the gently rolling character of the inter-stream surfaces, but we have a better view of the valleys which have been sunk beneath the general level and of the low rounded hills which rise above it. In popular parlance the country is "hilly." It is uneven, not because there are high hills, but rather because there are deep valleys. If in imagination we fill up these valleys and the wide Triassic lowland to the general level of the broad inter-stream surfaces, we shall have constructed a gently undulating plateau, dipping to the south and east—a peneplain.[1]

Origin of the peneplain. This is not a constructional surface, for the rocks are greatly tilted, folded and faulted, so that the surface consequent upon such disturbance must have been complex and mountainous. Long subaërial denudation upon a folded and faulted mass when the land stood much lower than

[1] Am. Jour. of Sci., 3d ser., vol. xxxvii, p. 430.

at present produced this plateau. Evidently it could be produced by denudation only at or near baselevel, for the effect of erosion upon a mass high above baselevel is to accentuate its topographic relief, not to reduce it. We naturally ask ourselves, "At what stage in geologic history did this denudation occur?"

Date of the peneplain. The erosion which accomplished this great work must have commenced after the formation and dislocation of the Triassic beds, for the even crest line of the trap ridges, a part of which—perhaps all—were contemporaneous with the sandstones, is a part of the dissected peneplain; but to fix the date of the completion of the peneplain, we must turn to evidence presented in New Jersey.[1] There we learn that by the close of Cretaceous times, the country was eroded nearly to baselevel, and we may therefore speak of the relative position of the land and sea, to which the land was at this time reduced, as the Cretaceous baselevel, and this land surface as the Cretaceous peneplain.

Elevation of the peneplain. In post-Cretaceous, presumably early Tertiary[2] times, the land was elevated to nearly its present height and remained at that altitude, so far as topographic evidence shows, during Tertiary times. The proofs of this elevation are the valleys which the streams have sunk below the general level. That this was not a simple uplift, but was accompanied with tilting and warping, is clear from the following considerations. The depth to which a stream can cut its valley depends directly upon its height above baselevel. If the present surface were a peneplain uniformly elevated, the head waters and middle courses of a river would not be cut so deep in the surrounding plain as its lower course. But the reverse is true of the rivers of Connecticut. The depth of the valley increases inland, being greater in those regions where the peneplain was raised the highest. A comparison of the upper and lower valleys of the Housatonic, Naugatuck, Quinnebaug, and of the

[1] Bulletin of Geol. Soc. of Amer., vol. ii, p. 554.

[2] It is not desired to affirm that these periods of erosion and elevation began and ended promptly with the beginning or end of a period. The time statements must be considered as only approximate.

Connecticut at Middletown, where it enters the plateau, and at its mouth, will give some idea of the amount of the warping. It will not give an *exact measure* of it for several reasons: first, the upper courses of the rivers have not yet reached the present baselevel; second, the present altitude of the uplands is the result of the post-Cretaceous uplift and warping, plus a probable later post-Tertiary uplift (to be mentioned later), besides several minor oscillations, the last of which was downward, and is recorded near the coast in the drowned condition of the rivers. As has been already said, the peneplain is highest in the northwest, and gradually declines to sea level toward the south and east.

Consequences of the uplift. The consequences of this uplift are seen in the valleys, which are cut into the peneplain, and which have destroyed the level character of the country. In the hard crystalline rocks the valleys are generally narrow and deep, with bold slopes;[1] where they are cut in the crystalline limestone, they are wider and more open. In marked contrast, however, is the lowland on the Triassic area in which only the trap ridges remain to tell of the former altitude of the general surface, and the immense amount of erosion which has taken place on the soft sandstones and shales. Indeed erosion has progressed so rapidly on these soft rocks, that they have been worn down almost to a new baselevel in the same length of time in which the hard crystallines have been only trenched. This fact cannot be too strongly emphasized. The broad sandstone lowland from New Haven north into Massachusetts has been carved out of the uplifted peneplain in soft rocks, during the same time in which the Connecticut has excavated its gorge in the crystallines below Middletown, and the Housatonic has opened its upland valley on the limestones. The difference in results is due not to

[1] An exaggerated idea must not be had of the steepness and narrowness of these crystalline valleys. The valley of the Farmington, five miles up from where it opens into the Triassic sandstone, is 400 to 500 feet deep, and a mile and a half wide at the top. The Connecticut valley, just below Middletown, is about 400 feet deep and two miles wide at the top. These are fair representatives of the valleys in the crystalline rocks in the central part of the state.

a difference of time, but to the difference in the relative hardness of the rocks.

On the basis of this principle the age of certain river gorges to which reference will be made later can be fixed. The *narrow* passage of the Quinnipiac through a sandstone ridge southwest of Meriden cannot belong to the same cycle of erosion as the *broad sandstone lowland* on either side of it, but manifestly must be much younger. So, also, the narrow passage of the Farmington at Tariffville, where it crosses the trap ridge through a gorge free from drift, is of much later date than the *broader* valley more or less encumbered with drift which the upper part of the same river has cut in the hard crystalline schists. Cook's Gap in the trap sheet west of New Britain is much broader than either of the above, and belongs to the Tertiary cycle of erosion, although as I shall endeavor to show later, it was probably not occupied by a stream during the whole cycle. In marked contrast, also, with the Tariffville gorge is the gap by which the Westfield river in Massachusetts cuts the trap ridge. This gap was formerly broad and open — the result of Tertiary erosion — but is now filled with drift, in which the river is at present working. Since these two rivers are essentially the same in size, are now at the same level, and the rock is the same in both cases, the only explanation for the difference in the two passages is that they belong to different cycles.

To recapitulate, the results of the post-Cretaceous uplift are seen in the valleys which have been cut in the peneplain. The narrow valleys in the gneisses and schists, the upland valleys in the limestones, the wide open, drift encumbered gaps in the trap ridge, — Cook's and the Westfield river gaps,— the broad open lowland on the sandstones, are all the result of erosion in this cycle. The Quinnipiac gorge in the sandstone, and the Tariffville gorge in the trap are just as surely of a later date. They do not at all accord with the work of the earlier cycle either in size, angle of slope, or depth.

This conclusion is somewhat at variance with an opinion expressed by Professor J. D. Dana,[1] but it seems justifiable in

[1] Amer. Jour. of Sci., vol. x, 3d ser., 1875, p. 506.

view of the successive cycles in the physical development of the region. In another part of this article I shall consider these gaps again in connection with their river histories, and shall give additional reasons why I venture to differ from so eminent an authority.

Length of this cycle. This cycle of erosion beginning with the post-Cretaceous uplift was not so long as the preceding cycle. In the earlier one the whole state was reduced to a peneplain; in the later cycle only the soft Triassic sandstones were brought near to baselevel. It probably lasted through Tertiary times, and was brought to a close by a slight uplift. The result of this uplift is well shown in Pennsylvania[1] and New Jersey[2] It is not well shown in Connecticut, but there seem to be some traces of it in the trenches the rivers have cut below the level of the sandstone peneplain. However, these trenches are so much obscured by drift that a positive statement is not warranted. It may, however, be spoken of provisionally as the post-Tertiary uplift. There may have been later oscillations of small amount, probably were; here and there are shreds of evidence which point to such oscillations, but only one movement has had an effect upon the topography, which can be recognized. The fjorded condition of all the rivers along the Sound—the Norwalk, Saugatuck, New Haven bay, Niantic and Thames are the best examples—shows that within comparatively recent time there has been a slight subsidence of the land. But this movement is not to be compared in amount with those of the earlier cycles.

The drift. Over all the state in varying thickness lies the glacial drift, either in its typical unmodified development as till, or in its modified form, as river terraces, kames, eskers and sandplains. It is of importance in this connection only as it has affected the topography of the country and so modified the drainage. Examples of these modifications will be mentioned later.

Résumé. There was first a long cycle of denudation in pre-

[1] McGee. Amer. Jour. Sci. 3d ser., vol. xxxv, p. 376.

[2] Davis and Wood, Geographic Development of Northern New Jersey, pp. 413, 414.

Triassic times, during which the contorted crystallines were worn down to a comparative level; second, a cycle of subsidence, deposition and volcanic outburst, during which the sea entered the crystalline trough, and the Triassic conglomerates, sandstones and shales were deposited with the intercalated layers of lava; third, a long cycle of elevation, folding, faulting and erosion, during which the sedimentary beds were elevated — tilted into the present faulted monocline, and this constructional surface worn down to a baselevel of erosion in late Cretaceous times. Each of these cycles probably represents the sum total of several subordinate cycles. There was, fourth, a post-Cretaceous uplift inaugurating a period of erosion lasting through Tertiary times and resulting in the formation of valleys in the hardest rocks, and a lowland approaching baselevel on the Triassic sandstones and shales; fifth, a probable late or post-Tertiary uplift, when the valleys were deepened and the lowlands trenched — obscure in Connecticut, but well shown farther south; sixth, the land, near the coast at least, is now slightly lower than it has been in the not remote past, as is shown by the fjords.

With the changes of the physical geography clearly in mind, the rivers of Connecticut may now be examined in respect to their conditions of origin, the number of cycles through which they have lived, and the approach they have made to mature old age. But at the very outset a serious difficulty is encountered, for the geological structure of the state is nowhere well described, nor have topographic maps of all the districts yet been issued. Since the structural details are to some extent unknown it is unwise in many cases to attempt more than tentative conclusions. Several of the problems to be presented cannot be considered as settled. Considerable progress toward a final settlement will have been made, however, if the conditions of the problems are made clear, various hypotheses suggested, and the attention of workers in this field called to these questions.

Early drainage. Of the drainage of Connecticut during Jurassic and Cretaceous times very little can be said. It is not even known whether it was consequent upon the Jurassic tilting

and faulting, or whether these deformations were so slow in their movement that the rivers persisted in spite of them. It may have been that the larger rivers were victorious, while the smaller were conquered and compelled to assume new consequent courses. Whatever was their origin there must have been abundant opportunities during the long erosion which resulted in the Cretaceous baselevel, and again in the period of revived and quickened degradation succeeding the post-Cretaceous uplift, for the streams to adjust themselves in a large degree to the geological structure. The contrast of hard and soft beds and the great elevation must have been potent factors in bringing to pass such a result. We expect to find the streams so far re-adjusted as to render improbable the discovery of their manner of origin.

The Housatonic, a re-adjusted stream. The best example of re-adjustment is found in the northwestern part of the state where the Housatonic and some of its branches follow well adjusted courses. From its headwaters, near Pittsfield, Mass., to New Milford, Conn., it has nearly all the way chosen its course along the Cambrian crystalline limestones in preference to the harder granites and gneisses on either side. The stratigraphical relationships of the limestone are not fully understood, but they seem to be deeply eroded anticlines and synclines, whose axes plunge north or south at various angles. The course of the river, if the drainage was consequent, was at first along the synclinal valleys, passing from one to another across the lowest points in the anticlinal ridge between them. But by a series of changes[1], resulting from the differential rates of erosion as hard or soft beds became exposed, the river previously to the Cretaceous baseleveling, seems to have re-adjusted its course to the softer limestones. However, there are several places where this conformity to structure does not seem to be the law; where the river departs from a limestone valley to flow for a time in the crystallines, only to return to the limestone again. The most marked instance of this is in the towns of Sharon and Cornwall,

[1] "Rivers and Valleys of Pennsylvania," Davis, W. M., published in The National Geographic Magazine, in 1889.

where the river leaves the limestone valley, which continues to the southwest, and flows for ten miles in a narrow gorge in the gneiss, only to again enter at its northern end a long narrow bed of limestone. The following seems to be the probable explanation. When the land stood at the elevation represented by the Cretaceous peneplain, these hard beds were below or but very slightly above baselevel, and were therefore undiscovered by the stream or had just begun to make themselves known late in the cycle. Had they been reached early in the cycle, when the stream was far above baselevel and presumably before many of its tributaries had been developed, and when it was therefore a smaller river, it is quite probable that further re-adjustments would have occurred, and the stream been led away from the hard rocks onto the softer beds to the west; but when they were reached the stream had cut so deeply and so nearly to baselevel that it was safe from capture. After the elevation of the peneplain the stream was revived and disclosed more and more of these hard beds, but was then, owing to the development and head-water growth of its tributaries, too important a river to be diverted by any rival. A river of this kind may be said to be "conformably superimposed" in distinction to one which is superimposed from an uncomformable cover.

Revived streams. It is important to recognize the effect of the post-Cretaceous uplift upon the rivers at that time established. As the land was baseleveled and the velocity of the streams decreased, they lost in large degree their cutting power and sluggishly meandered more or less in broad flood-plains. During and for a period after the uplift, their cutting power was restored to them by virtue of their increased velocity and they excavated the deep narrow valleys which we find in the crystalline highlands. The upper course of the Housatonic is a good example of a river re-adjusted to the structure during one cycle, revived by uplift to a second cycle of erosion, and in places "conformably superimposed" upon structures from which it would have been led away in the ordinary course of re-adjustment. Its tributaries, the East Aspetuck, Still, Shepaug, and Pomeraug

follow courses re-adjusted in one cycle and revived in a later uplift.

We can assert with the more confidence that such was the history of the upper Housatonic, because we find in other states, in regions whose history has been the same, similar examples of "conformably superimposed" and "revived" streams. The Musconetcong and Pequest, highland rivers of New Jersey, are streams "revived" from mature old age to vigorous youth and "conformably superimposed" upon saddles of gneiss between two limestone valleys.[1]

Unconformable rivers. In considering the course of the lower Housatonic we meet with some difficulty at the outset. In the southern part of the town of New Milford the river leaves the limestone belt which continues with some slight interruptions to the Hudson, and swings sharply into the crystalline plateau in a southeasterly course until it is joined by the Naugatuck, when their united waters flow south for a few miles to the sound. The course of the lower Connecticut is even more surprising. At Middletown it leaves the broad open Triassic sandstone lowland, and through a gorge enters the plateau, which has an average elevation of 600 to 700 feet. In this plateau of crystallines the river has sunk its valley nearly to sea-level. The slopes are steep compared to the lines in the sandstone lowland, and the contrast between the two parts of the river is one of the striking features of Connecticut scenery. Several theories may be framed to account for the curious behavior of these two rivers, but none of them are free from all difficulty.

As a consequent river. The lower Connecticut has been thought[2] to be a revived river, whose course was consequent upon the post-Triassic tilting and faulting. The faulted monocline seems to have had the shape of a half-boat, ends to the north and south, and one gunwale rising toward the west, the combined effect of the tilting and faulting being to swing the river to the southeast, where the keel of the boat was lowest. The proba-

[1] Davis, W. M., "Geographic Development of Northern New Jersey," p. 397-8.

[2] Davis, W. M., Amer. Jour. of Sci., 3d Ser. vol. xxxvii., 1889, p. 432.

ble existence of faults, with upthrow on the east, along the eastern margin of the Triassic rocks, is a difficulty in the way of the complete acceptance of this theory. Unfortunately too little is known about the structure of the western plateau to say whether the course of the lower Housatonic could be accounted for on such an hypothesis. On this theory the Connecticut would be consequent upon the Jurassic deformation, and revived by the post-Cretaceous uplift.

It may be suggested that the southeast courses are due to the tilting of the peneplain at the time of elevation, the plateau now being, as we have seen, much higher in the northwestern part of the state than elsewhere. But the acceptance of this theory necessitates a degree of smoothness and absence of even mild relief in the peneplain, which is hardly possible. The present average slope of the plateau is but a few feet per mile, and it seems incredible that so gentle a tilting could force rivers as large as these to take new courses. Besides, if the Housatonic and Connecticut were deflected, why were not the smaller streams—the Naugatuck and Quinebaug—also given south-eastern deflections? Clearly, this explanation is not the correct one.

Superimposition. It has been suggested that these courses may be inherited from a Cretaceous cover, which formerly stretched over Connecticut for a considerable distance, but of which no traces now remain in the state. On parts of Long Island the Cretaceous deposits are found, and it is not inherently impossible nor improbable that they once stretched far over the main land. In New Jersey[1] several lines of evidence seem to show that the Cretaceous beds formerly extended across the Triassic, probably to the margin of the highland plateau. The curious drainage of the Watchung Crescent is one evidence of this, but the other proofs are along entirely different lines, so that there is apparently good evidence that the Cretaceous beds

[1] Geog. Devel. of Northern New Jersey, p. 404 et seq. Proc. Bos. Soc. Nat. Hist., Also Rivers of Northern New Jersey, p. 11 et seq. National Geographic Magazine, vol. ii, p. 93.

extended twenty-five miles or more farther inland. If, in the time which has elapsed since the deposition of these beds, there has been erosion sufficient to strip them off from such a broad area in New Jersey, may they not, in Connecticut, under presumably similar conditions, have been equally eroded ?

There is much which makes this hypothesis attractive, and, as the facts were first studied, it seemed the most likely one. It affords a good explanation, not only for the courses of the Housatonic and Connecticut, but also for other rivers along the sound. It seems, also, at first thought, to be well supported by analogy from New Jersey. But a closer study of the situation in that state reveals marked differences in the attendant circumstances. There the soft Triassic sandstone must have been worn down to a lowland early in the Cretaceous cycle, perhaps by the close of Jurassic time or thereabouts, while the harder crystallines retained a strong relief. The slight subsidence, which marked the beginning of marine Cretaceous in New Jersey, allowed the Cretaceous sea to transgress rapidly the baseleveled sandstones to the foot of the crystalline hills, but not to cover them to any extent. It is not probable that the crystallines in Connecticut had been brought nearer to baselevel than those in New Jersey at the time of the Cretaceous deposits. There is no evidence to show that the subsidence was greater in Connecticut than in New Jersey, and, therefore, from *a priori* considerations, the conclusion would seem to follow that the subsidence, which permitted the Cretaceous sea to cover the Triassic sandstone area of New Jersey, was not sufficient to permit the sea to cover the then unsubdued crystalline hills of Connecticut. Although this hypothesis is not to be hastily thrown aside, for theoretical reasons, yet it would seem necessary to hold it very lightly, at least until some positive proof is found of the former existence of the Cretaceous or some later formation in that region. The first suggestion, that the lower Connecticut was a consequent river in the Cretaceous cycle and was revived by the post-Cretaceous uplift, is, at the present state of knowledge, the most probable.

The Farmington. The roundabout course of this river pre-

sents another interesting problem, which is not free from difficulties. From its source in Massachusetts it flows southeast across the crystallines to the village from which it takes its name, where it turns abruptly north along the Triassic sandstones for ten or twelve miles, when with another wide sweep it crosses the trap ridges at Tariffville by a deep gorge. and resumes its southeasterly course to the Connecticut. Of this latter part I will speak later, but now arise the questions, "what has been the history of this river," and "why does it turn north at Farmington?"

The Farmington in the Tertiary cycle. A course more accordant with the structure would seem to be south along the Quinnipiac and Mill river valleys to the sound at New Haven. As has been said before (page 376), Prof. Dana has expressed the opinion that the gorge at Tariffville was occupied by the Farmington in Tertiary times, and that the Westfield river gap further north and the gorge of the Quinnipiac southwest of Meriden are also of earlier date than the glacial epoch. One reason has also been given why I differ from him in regard to the Quinnipiac and Tariffville gorges—they are narrower and steeper than those made in similar rocks during the Tertiary cycle. But more than this, the constructional topography, resulting from the tilting and faulting of the region, could not, it would seem, have caused the Farmington to take its present course. Even if it had taken this roundabout course during the baseleveling of the country, it must, since it would have had to cross three trap sheets, have been captured and led to the sea by the shorter and easier way along the sandstone area. The fact that the Connecticut probably persisted in its consequent course is no argument for similar conditions for the Farmington, because the latter is much the smaller stream, and so more easily captured. Nor could the river have been forced into this course during or after the post-Cretaceous uplift, for the land was then raised more at the north than at the south, and any changes from this cause would have been to confirm the river in its southward course. It is very probable, therefore, that in at least the latter

part of the Tertiary cycle, the Farmington did not have its present course, but followed the open sandstone valley, along the course of the Quinnipiac and Mill rivers of to-day. The earlier history of this river is purely conjectural; one fact may shed a little light upon it, a fact which may indicate that this course was an adjusted one taken during Tertiary times.

In pre-Tertiary times. Origin of Cook's Gap. A few miles southeast of where the river emerges from the crystallines, the trap ridge is cut by a deep wind notch—Cook's Gap—through which the New York and New England Railroad passes west from New Britain. As was pointed out some time ago by Prof. Davis,[1] this is not a fault gap, because the alignment of the ridge is not broken, but it is probably an abandoned water gap, the head-waters of the stream which formerly occupied it having been abstracted by a rival, which did not have to cross a hard trap ridge. Perhaps this river was the ancestor of the present Farmington, and in that case its history would seem to have been as follows. A stream consequent upon the constructional topography after the faulting and tilting at the close of the Triassic, it had its upper course on the crystallines, its lower on the sandstones and buried trap sheets. In its old age it crossed by a shallow gap the trap sheet, which had been uncovered by erosion. In the second or Tertiary cycle it was simply a revived stream quickened to a new life by the post-Cretaceous uplift of the peneplain. This uplift gave opportunity to a rival stream, which did not have to cross the hard trap beds to intercept the waters of the old Farmington, and lead them out by a shorter, easier path, probably down the sandstone valley west of the trap ridge. The path across the trap was abandoned, and the notch became a wind gap; the river following its new course, until the incursion of the ice-sheet interrupted its normal development. This is of course almost entirely speculative. Cook's Gap is best explained as an adandoned river gap; the Farmington is the nearest river of a size proportional to the size of the gap, and the

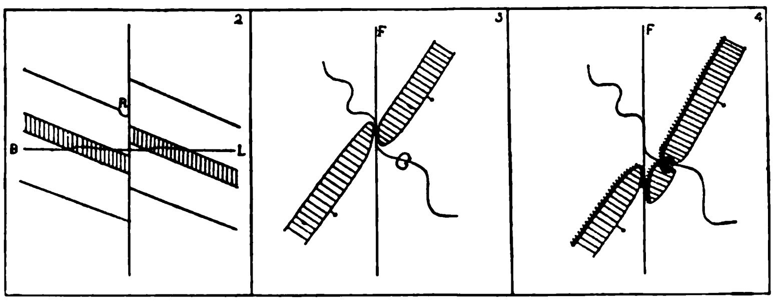
[1] Faults in the Triassic Formation near Meriden, Conn. Bulletin of the Mus. Comp. Zoöl. Harvard Univ. vol. xvi. No. 4, p. 82.

hypothesis is a rational one. There is, however, no direct evidence that the Farmington once occupied Cook's Gap.

The Tariffville cut. Before attempting to answer the second question, "why the river flows north at Farmington?" let us consider for a moment the history of the Tariffville cut. The river occupies a gorge whose sides are steep and talus covered, but which is not at all clogged with drift. There is naturally no room at or near the water level, even for the wagon road, place for which has been blasted near the top of the gorge. The profile of the gap shows a gentle ascent from the top of the gorge, up to the nearly level crest line of the ridge. That is to say, the recent gorge has been cut in the botton of a sag in the ridge. We have already given our reasons for believing that the gorge here is much younger than the Westfield river gap; that it is a part of the work of the next cycle; that it is post-Tertiary. The sag, however, in the bottom of which the gorge is cut, is clearly of the earlier cycle. The bottom of the sag is much above the level to which the rivers had cut their valleys in the late Tertiary, and, therefore, it is certain that a river could not have occupied it at the close of that cycle. It was probably an abandoned water-gap whose stream had been captured in the same way and in the same cycle as the river, which formerly occupied Cook's Gap.

The fact that the sag and gorge, although located very near a fault line, do not correspond to it, but are transverse and independent of it, is instructive and needs a moment's attention. It seems probable that the stream consequent upon the faulted blocks would have flowed down the slope of the tilted block and then along the fault line at the foot of the fault cliff and would have held this course during the baseleveling of the country. When the area was baseleveled the stream must have swung from side to side in its broad flood plain, and thus departed from the fault line. When it was revived by the post-Cretaceous uplift, it was confined to the course it had unwittingly taken on the sandstones just above the hard ridge, and it was forced to cut down through the trap. Subsequenlty a rival, which did not have

to work against this obstacle, abstracted its head waters and the gap was abandoned. The accompanying diagrams may make this easier to understand. Figure 2 is a cross-section of the faulted monocline, R showing the position of the river along the foot of the fault cliff. The line B L represents the surface of the country after baseleveling, the trap outcrops forming *low* hills (much exaggerated in the diagram). Figure 3 shows the dislocated trap sheets, the fault line and the winding course of the river, which has abandoned the fault line except where it passes between the low trap hills. Here the country is at base-level. Figure 4 represents the region after the elevation and resulting erosion. The trap ridges have become more pro-



FIGURES 2–4.

nounced, and have migrated eastward in the direction of the dip. The river has been slowly let down upon the northern one from the sandstone at point G and has there cut into the solid trap.

The transverse notch of Cook's Gap, already described, was probably located in a somewhat similar manner, but the case is not so clear as at Tariffville.

Gravel terraces of the Farmington. A consideration of some facts concerning the height and slope of the terraces along this part of the river may give a clue to the answer to our question. One-half a mile east of Tariffville and east of the trap ridge, the highest terrace is 210 to 215 feet. Half a mile south of the same place but west of the ridge the height is 275 feet.[1] The

[1] J. D. Dana, Amer. Jour. Sci. 3d. ser., vol. xv, p. 506.

top of the gorge at Tariffville is about 190 feet above the sea-level. It does not seem probable that these highest terraces were ever continuous over all the Farmington valley. But if they represent the level reached by the maximum flood accompanying the melting of the glacier, the great difference in their height on the two sides of the trap ridge, in connection with the other evidence already noted, gives strong reason for believing that the gorge as it exists to-day had not then been cut. A mile and a half east of Tariffville there is a lower terrace which is wide-spread. Its general height is about 190 feet, in places a little more. In this terrace the lower part of the Farmington has cut a trench 90 to 100 feet deep. The shape of the valley makes clear the fact that before this trench was cut the river flowed at about the 190 foot level, which is the height of the bottom of the sag at Tariffville. On the west side of the trap ridge there is also a more or less wide-spread terrace at about the same height. It seems very probable therefore that the river was raised to the level of the old sag in the trap ridge by the building of these terraces.

The present average southward slope of the highest terraces west of the trap ridge from Northampton, Mass., to Farmington, Conn., forty-four miles, is seven inches per mile,[1] and Professor Dana is inclined to believe that this is approximately the slope at the time the terraces were built. The character of the deposits shows that the current which formed these deposits flowed south. The present river, flowing north, falls twenty feet between Farmington and Tariffville, or 1⅔ feet per mile. The reversal of the river was probably determined by two factors. Near the village of Farmington, the waters of 200 square miles of territory are poured into the valley by the upper Farmington and its tributary, the Pequabuck. During the terrace building stage the great mass of débris contributed by these streams was deposited where the steep gradient of the highlands was exchanged for the gentle slope of the lowland. The main north and south valley was thus choked by the débris of its tributaries

[1] J. D. Dana, Amer. Jour. of Sci. 3d ser. vol. xxv, p 446.

and a long stretch of comparatively still water extended north from Farmington, in which nearly horizontal deposits were made. South of Farmington the terrace deposits are much coarser than to the north, and the face of the terraces is much greater. It is not impossible that, as the deposits between Farmington and the Massachusetts state line approached nearer and nearer to horizontality, the waters of the upper Farmington began to divide, part flowing north and part south, the northward flowing portion finding an outlet at the sag at Tariffville. If this was the case, the terraces between Farmington and Tariffville must have had a slight slope to the north. Their present southward slope could readily be accounted for by the re-elevation of the land after the disappearance of the ice. This explanation rests upon the ability of the upper Farmington and the Pequabuck to have completely dammed the southward flowing current and turned it northward by the great mass of their deposits. If this was not the case, and there may be some doubt on the matter, the subsidence which accompanied the later stages of the ice-retreat is the other factor in the problem. It is estimated that an average depression of 1.25 feet[1] through the Connecticut valley would restore it to an altitude approximating that at the close of glaciation. It seems highly probable that these terrace-deposits were built before the maximum depression was reached. If this was the case, the depression would be efficient in reversing the Farmington, and this factor would supplement the first. It is impossible at present to say to what extent these two factors enter into the problem. That they are not mutually exclusive is evident, and that they are together quantitatively competent seems certain. Among the several hypotheses which have been considered, this seems the most probable, and in the light of the present evidence the most rational.

At first thought it might seem that if the Farmington was reversed by the differential subsidence of the land, the Connecticut ought to have suffered a similar fate, and since it did not, the explanation cannot apply to the Farmington. But

[1] J. D. Dana, Amer. Jour. of Sci., 3d ser., vol. xxiii, p 198.

the terraces of the Connecticut have a much greater southward slope than those on the smaller river, and the depression was not sufficient to reverse the stream. The conditions on the two sides of the trap ridge were not the same.

To sum up, then, the history of the Farmington seems to have been as follows: Its original consequent course was southeast on the crystallines and perhaps across the trap ridge at Cook's Gap, from which course it was turned in the Tertiary cycle by a stream whose course was approximately that of the Mill river of to-day. The damming of the valley by the deposits of the Upper Farmington, and the depression in the north accompanying the ice retreat, reversed the river at Farmington, and it took a new course on the terrace deposits, escaping by the sag in the trap at Tariffville into the Connecticut valley.

The Quinnipiac. The gorge of the Quinnipiac, already mentioned several times, seems closely comparable to the gorge of the Farmington. It is not of the Tertiary cycle, and is best referred to the inter-glacial or post-glacial epochs. We should expect the Quinnipiac, instead of turning eastward, to cut through this sandstone ridge, to continue southward along the Mill river valley. Dana[1] finds from the heights of the terraces that the drainage of the terrace-building period was not along the Quinnipiac, but along the Mill river, and concludes that the Quinnipiac gorge was obstructed by an ice-dam. I have not as yet studied it enough in detail to do more than express the opinion here reiterated, that this gorge is later than the cycle in which the open sandstone lowland on either side of it was excavated. Its topographic form would put it in the cycle which has been called post-Tertiary.

The Scantic. In the Scantic we have a typical example of a river whose lower course is manifestly of a later date than the upper. In this it is similar to several of our Atlantic rivers, notably those of North Carolina, whose upper courses are on the Piedmont crystallines, being probably established previous to the Cretaceous baselevelling, and whose lower courses stretch

[1] J. D. Dana. Amer. Jour. Sci., 3d ser., vol. xxv, p. 441.

seaward over the unconsolidated Tertiary deposits of the coastal plain. As the plain of these recent deposits emerged from the sea, the rivers were forced to extend their courses eastward over the freshly raised surface to the retreating shore line. The Scantic river has a similar history. Its upper course in southern Massachusetts on the crystalline plateau is a remnant of the drainage established before Cretaceous baselevelling and revived by the subsequent uplift. How much that revived drainage has been modified by drift can only be determined by long field study, but the topography, as read from the topographical atlas would seem to indicate, that it has not been much. The valleys were undoubtedly clogged with drift, and the drainage area may be somewhat modified, but the drainage seems to be substantially along the same lines.

Just below the village of Hampden, the Scantic leaves the plateau and enters the Triassic lowland. From this point to its mouth at the Connecticut, opposite Windsor, a distance of twenty miles, it flows nearly all the way through the gravel, sand and clay deposits of the period of ice-retreat. The topography of the lower course of the river is entirely characteristic of a stream which has recently attacked a level, easily eroded district. The inter-stream surfaces are broad and flat; the descent to the stream bed which is sunk seventy or eighty feet below the general surface is exceedingly steep. These two lines, that of the inter-stream surface and that of the valley side, meet at a sharp angle. The side streams are as yet very short, and have cut narrow gorges down to the main river. Tributary to them are deep side ravines, whose bottoms ascend rapidly to the inter-stream surface, the whole making a dendritic system of drainage in its earlier stages. The Scantic, having reached base level in its lower course, has developed a narrow flood-plain.

Manifestly this part of the river valley is of much later date than the upper part. If, during the period of ice-retreat, the lower Connecticut valley was an estuary, the Scantic was a much shorter river than at present. Its mouth could not have been far from the point where now it leave the crystallines, but as the

land was elevated and estuarine conditions gave place to fluviatile, the Scantic lengthened "mouthward," consequent upon the minor inequalities of the newly made beds. The effect would be substantially the same if the terraces were built by great valley floods, as Dana supposes. In pre-glacial times this river, in common with several other rivers rising on the crystallines and flowing into the Connecticut, had courses of various lengths over the Triassic sandstones, but these old valleys are lost entirely, the later trenches in the terrace deposits being altogether independent of them.

Other examples. The lower Hockanum, Farmington, Park, and the entire length of many short streams are similar to the lower Scantic, and originated under similar conditions. Stony Brook, a little stream north of Windsor Locks, presents the same features, but with this variation: It is superimposed through a thin layer of drift upon the sandstone, into which it has cut a deep, picturesque gorge. The Hockanum and Farmington are also "locally superimposed" in a few places. The Connecticut, also, north of Middletown, although following its pre-glacial valley, has departed in numerous places from its former bed, and has cut down through the valley-filling onto ledges of rock beneath. The water-power at Enfield, Conn., and at Turner's Falls and Bellows Falls, Mass., is the result of this superimposed position.

Abandoned gaps. Many abandoned water-gaps must exist among the hills of the state. Cook's Gap, through which the New York and New England Railroad crosses the trap ridge, three miles west of New Britain, has already been discussed. It must not be confounded with the majority of the other gaps in the trap ridge, which are oblique, break the alignment of the ridge, and are due to faults.

The New York and New England Railroad in ascending to the eastern plateau passes through Bolton Notch, a few miles east of Manchester. This notch, also, is an abandoned river bed but, as it seems, abandoned at a later date and for another reason than that assigned for Cook's Gap. The drift is very heavy in

this region, and the most probable explanation is that the post-glacial streams do not altogether follow pre-glacial valleys. This gap, used by turnpike and railroad, testifies of another and older drainage system.

That in this brief article all the problems connected with the Connecticut rivers have been solved, or even noted, is not to be expected. It is hoped, however, that the work done may prove a help to further study of the same regions, and that the tentative conclusions advanced may be substantiated by further investigation.

HENRY B. KUMMEL.

STUDIES FOR STUDENTS.

GEOLOGICAL HISTORY OF THE LAURENTIAN BASIN.

THE study of the Pleistocene history of the basin drained by the St. Lawrence has been fragmentary and is still far from being complete. There is a lack of agreement in the interpretation of observations already made, due in part to the comparatively limited portion of the field examined even by those who have given the subject most attention, and in part to lack of uniformity in the standards of comparison used. It is with the hope of assisting in reaching more harmonious results that attention is here invited to methods of study.

In the present treatment of the subject it may be advantageously subdivided, and the facts and hypotheses relating to each division separately considered. Of the divisions that may be suggested the following seem the most important:

1. Character of the sub-morainal or hard-rock topography in the Laurentian basin.
2. Origin of the basin.
3. Sedimentary deposits.
4. Shore markings left by former water-bodies.
5. Fossils in ancient sediments, shore ridges, terraces, etc.
6. Fauna of the present lakes.
7. Changes in elevations of the land.
8. Former outlets.
9. Probable effects of an ice sheet on drainage.
10. Probable effects of a subsidence which would make the basin an arm of the sea.

1. *Character of the hard-rock topography.* In order to learn the character of the Laurentian basin it is necessary to

examine the rock surface beneath the general covering of glacial débris and stratified sediments which partially fill it. To do this, those areas in which rock in place forms the surface require to be mapped and their elevations noted; the records of wells and other excavations which pass through the superficial deposits should also be obtained and the character of the underlying rock ascertained, as far as is practicable. When sufficient data of this nature shall have been recorded, a contour map of the basin can be drawn that will reveal the shape of the depression with which the student has to deal. The depth of the present lakes plus an estimated thickness of clay and morainal material covering their bottoms, will probably furnish the only means of sketching contours over the deeper portions of the basin. Even an approximately accurate map of this character cannot be constructed for a long time to come, but every advance towards it will serve to make the problems to be studied more and more definite.

Something of the form of the rock-basin is already known and several deep channels in its borders, now filled with drift, have been discovered. The courses of buried channels connecting the basins of some of the present lakes have also been approximately determined. It is not necessary at this time to refer specifically to the discoveries that have been made, but it may be stated that enough is known to assure us that the basin is a depression in solid rock, the bottom of which is below sea level.

2. *Origin of the basin.* The rocks in which the Laurentian basin is situated are, with the exception of the Lake Superior region, nearly horizontal and belong almost wholly to the Paleozoic. The basin is essentially a depression in undisturbed strata, and all who have considered its origin seem agreed that it has been formed by excavation. A vast mass of horizontal strata has been removed, leaving an irregular rim of undisturbed rocks on all sides. The form of the depression is now obscured by drift; the deeper portions contain stratified sediments which have been deposited within it and it has been warped somewhat by orographic movement.

The manner in which the excavation was formed has been explained principally in two ways. One hypothesis is that it owes its origin to a time of subaërial denudation preceding the Glacial epoch, during which a valley, or series of valleys, was worn out by stream erosion; and that the depression thus produced has been but slightly modified by ice action. The closing of the ancient valley has been referred to orographic movements and to the filling of its outlet by glacial débris. Another hypothesis is to the effect that the excavation is mainly due to ice erosion during the Glacial epoch, without special reference to previous topographic relief. A warping of the earth's crust so as to produce a true orographic basin does not seem to require consideration, for the same reason as already stated, that the rocks in which the basin lies have been but little disturbed from their original horizontal position. Future study of the region must determine which of the two hypotheses outlined above best suits the facts; or if each hyphothesis has something in its favor, what combination of the two may be accepted as the final explanation.

It is a suggestive fact in connection with the first of these hypotheses, that the youngest rocks in the region antedating the Pleistocene belong to the Carboniferous. This seems to show that the land has not been submerged since at least the close of the Paleozoic. If not a region of sedimentation during this vast interval, it must have been subjected to erosion. The erosion of an ancient land surface might result in the production of topographic forms of diverse character, depending on its altitude, on the length of time it was exposed to atmospheric agencies during various stages of elevation, and on climatic and other conditions. The study of topographic forms is now sufficiently advanced to enable one to predict somewhat definitely what features would appear under certain conditions. We also know the characteristics of topographic forms due to glacial erosion. It seems evident, therefore, that a knowledge of the hard-rock topography in the Laurentian basin, would enable one to draw definite conclusions in reference to the part that ice and water each had in shaping the forms now found there.

The conclusion that the region under consideration has been glaciated is well established; it remains, therefore, to determine what topographic forms, if any, due to pre-glacial stream erosion can be recognized. As an example of this kind of evidence desired, attention may be directed to the northward facing rock escarpments which follow the southern shores of lakes Erie and Ontario for a large part of their courses and at varying distances up to several miles. These escarpments are composed of the edges of nearly horizontal strata, mostly of Paleozoic limestone, and their bases are buried beneath glacial debris and stratified clays so deeply that in some instances, at least, they do not reveal half of their actual height. These escarpments not only have Pleistocene deposits banked against them, but their faces and summits are polished and grooved, showing how stubbornly they resisted the invasion of the ice which impinged against them from the north. South of lake Ontario especially, the trend of the escarpment referred to is directly athwart the course of the ancient glaciers. The entire history of these escarpments cannot be discussed here, as my desire is simply to call attention to the fact that they existed before the Glacial epoch, and are relics of a strongly accented pre-glacial topography. They are within the southern border of the Laurentian basin, and hence afford means of determining, in part, what was the form of that basin before it was modified by ice action. Other similar escarpments exist in the northern and western portions of the same great basin, and as this study progresses it is to be expected that still other features of the pre-glacial land will be revealed. It is perhaps too early to decide what were the special topographic forms which gave character and expression to the St. Lawrence basin before the ice invasion, but the Erie and Ontario escarpments and some other similar features now recognized, suggest that in Tertiary times it resembled the present condition of the upper portion of the Mississippi valley, where bold, rock escarpments border wide stream-worn depressions.

Deep drift-filled channels are known to cut across the Erie and Ontario escarpments. These seem to have been formed

by streams tributary to the main drainage line to the north. If this conclusion is well founded, a study of the hard-rock topography should reveal other similar channels and finally indicate a well matured drainage system. If even the broader and stronger features of the pre-glacial surface can be determined, then the modifications due to glacial abrasion will become conspicuous, and the amount that glaciers have broadened and deepened the basin be determinable.

A study of the lithological character of the drift south of the present lakes should show, at least in a rough way, what portion of it was derived from the waste of rocks within the Laurentian basin. This inquiry has already been undertaken by at least two geologists, and estimates of the quantity of material removed from the basins of lakes Michigan and Erie respectively, have been made. This method may be extended so as to embrace a larger area, or some special portion of the great depression best suited for the trial may be selected. If the material removed from the basin or re-distributed within it by glacial action can be shown to be approximately equivalent in volume to the amount of rock excavated in order to form the depression, it would evidently tend to support the hypothesis of glacial erosion. If, on the contrary, the amount of débris derived from the basin should fall far short of what would be requisite to refill it, no very definite conclusion would seem to be indicated unless account could also be taken of the fine material carried away by glacial streams.

As the case stands at present it appears that there is evidence of a pre-glacial valley or series of valleys as has been claimed by several geologists, and that all but the boldest features of the old topography have been obliterated or greatly modified by glacial erosion followed by glacial and other sedimentation. Additional observations should show somewhat definitely the amount of work assignable to particular portions of the history. How far the results of subaërial and of glacial erosion have been modified by other agencies, more especially by orographic movements, has also to be considered.

If the St. Lawrence basin shall be shown to be largely the

result of subaërial erosion it will follow, unless it is found that the deeper portions are the result of glacial action, that the land at the time the streams did their work, must have stood higher than at present, for the reason that the bottom of the depression is now below sea level. Some idea of the smallest amount of elevation necessitated by this hypothesis might be obtained by estimating the gradients of the ancient streams and the amount of elevation required to bring the bottom of the depression up to sea level.

A study of the hard-rock topography in the valleys of the Ottawa and St. Lawrence and of the present submerged Atlantic border of the continent would also be instructive in this connection. The strict correlation of the topographic history of the interior and of the continent's margin may be difficult, but as the two regions are directly connected, valuable results should follow their comparative study.

The hypothesis that the Laurentian basin is due largely to preglacial erosion, necessitates also that the ancient system of river valleys should have been closed in some way so as to form the basins of the present and of former lakes. The closing has been referred to several agencies. An unequal subsidence following the period of stream erosion has been postulated. During the Glacial epoch the entire region was ice-covered and only glacial streams of one kind or another could have existed. On the retreat of the ice, when portions of the basin were abandoned, the drainage is supposed to have been obstructed by the ice itself, as will be noticed below. When the glaciers melted, a vast sheet of débris was left which in many instances filled or obstructed previous drainage lines. Old channels, now deeply buried, have been reported to connect the basins of the various existing lakes, as has already been mentioned, but no similar channel which could have afforded an escape for the waters of the entire basin has been discovered. Here again an acquaintance with the hard-rock topography should give assistance and indicate either that such a channel existed or that orographic movements have taken place which have obstructed the former drain-

age system. The glacial hypothesis assumes that the basin was excavated mainly by glacial abrasion and does not require that the land should be either higher or lower than at present. The study in this direction merges with that of the general glaciation of the northeastern part of the continent, and cannot be treated at this time.

3. *Sediments.* — Regularly stratified deposits of clay and sand occur along many portions of the borders of the present Laurentian lakes. These were clearly formed in water bodies which formerly existed within the Laurentian basin, and which in certain directions, at least, were of wider extent than the present lakes. The areas occupied by these deposits have been partially mapped, but much remains to be done in this direction. Fresh sections, particularly of the stratified clays, are exposed from time to time by artificial excavations, in which much of their history may be learned. Not only should records be made of the facts noted at special excavations, but the extent and character of the stratified deposits in one area should be determined and compared with similar data obtained in other areas. For example: the clays covering large tracts on the west shore of Lake Michigan and on the southern and western border of Lake Superior are of a red color, while other areas bordering Lake Erie are covered with blue clay. These two deposits have been supposed to have been laid down at the same time and in the same lake. The definite correlation of the clays of these two areas by direct contact, however, does not seem to have been made, and there are reasons for thinking that they may be quite distinct and that they originated in separate lakes.

The outer limits of the deposits of clay and sand here referred to are known in some instances to be determined by ancient beaches and terraces. Such associations of deep and of shallow water deposits require special attention, as the study of one may assist in interpreting the significance of the other. The fine, evenly stratified clays frequently contain large angular bowlders, which appear to have been dropped from floating ice and to show an intimate connection between the

ancient lakes and neighboring glaciers. The possibility, however, of the bowlders having been brought into the ancient water bodies by rivers, or floated outwards from the shore by lake ice, should also be considered. Huge angular masses of limestone have been reported as occurring in southern Michigan especially, which rest on superficial deposits and are thought to have been carried northward by lake ice. The relations of these masses to well defined shore lines have never been determined. If it should be found that they are above all former shores, it is evident that they must have been carried by some other agency than the one mentioned.

A chemical examination of the clays, or of their contained water, may indicate whether or not the basin was formerly in direct communication with the ocean. Analyses of the clays of the Champlain valley and of the similar clays in the Ontario and Erie basins might indicate whether or not they were deposited under similar conditions.

4. *Shore records.* Beaches and terraces have been studied at many localities about the borders of the present lakes, sometimes at a distance of more than twenty miles from their margins and at various elevations up to several hundred feet above their surfaces. In some instances these ancient shore records have been followed continuously for scores of miles. The tracing and mapping of individual beaches is one of the most important parts of the study here outlined, and is already well advanced. Confusion has unfortunately arisen, however, for the reason that topographic features, due to shore action, have, in some instances, been confounded with somewhat similar features due to other causes. Moraines and gravel ridges, formed by glacial streams, have been mistaken for beach ridges, and terraces of various origin have not been clearly discriminated.

In order not to be led astray by topographic forms that simulate shore phenomena, the student should examine the shores of existing lakes and learn what records are there being made. In the study of topography, "the present is the key to the past," just as definitely as in any other branch of geology. The

topography of lake shores has already received attention from one skilled in reading geological history in the relief of the land[1] and the study of existing shores in the light of what has already been done in that direction should enable even the beginner to avoid falling into serious error in interpreting ancient records of the same nature.

To be able to discriminate clearly between shore features and somewhat similar glacial phenomena, it is necessary to become familiar also with the topography of glacial deposits. Fortunately in this study also a guide is at hand[2] which, in connection with field observations, should soon train the eye to discriminate the shapes assumed by moraines and the deposits of glacial streams from all other topographic forms.

In examining the records of former lakes it will soon be observed that, in many instances, where the highest of a series of ancient beaches is obscure and indefinite, the topographic expression above and below a certain horizon, and also the character of the surface material, whether of the nature of lacustral clays and sands or of glacial débris, residual clay, etc., above and below the same level, are significant, and enable one to map the outline of a former water body with considerable accuracy.

In tracing ancient beaches and terraces, their forms and internal structure need to be recorded, so that the fact of their being true shore records may be made plain to others. The elevations of various well-defined points throughout the extent of an ancient shore should be carefully measured, for, as will be noticed below, although originally horizontal, they have, in many instances, been elevated or depressed, owing to broad general movements of the earth's crust. The continuous tracing of individual shore lines for as great a distance as possible is highly desirable, especially in a wooded country, in order to be positive as to which ridge or terrace measurements of elevation relate, and and also for the purpose of observing the nature of the changes that

[1] The Topographic Features of Lake Shores, by G. K. Gilbert, in Fifth Ann. Rep. U. S. Geological Survey 1883-4.

[2] Preliminary Paper on the Terminal Moraine of the Second Glacial Epoch, by T. C. Chamberlin, in Third Ann. Rep. U. S. Geological Survey, 1881-2.

occur when a shore line gives place to other records. For example: some of the ancient beach ridges about the west end of Lake Erie have been found to be continuations of moraines. In other instances shore ridges have been reported to end indefinitely and to be replaced at the same general horizon by glacial records of various character. The correct interpretation of phenomena of this nature is especially important.

Accurate measurements of the vertical intervals between well defined beaches at many localities would enable one to identify special horizons, providing orographic movements were not in progress during the time the series was forming. This method has recently been successfully applied on the north shore of Lake Superior, where the character of the country does not admit of the tracing of individual terraces for considerable distances.

The deltas of tributary streams should also be revealed in the topography of the basin of an ancient water body. Changes in the character of lacustral sediments near where rivers emptied are also to be looked for. Sand dunes are frequently an important accompaniment of existing shores, and their association, perhaps, in a modified form, with ancient beaches is to be expected.

5. *Fossils.* Thus far only a few fossils have been found in the stratified clays and sands or in the ancient beaches of the Laurentian basin. Such observations as have been made in this connection indicate an absence of the remains of marine life and the presence, in a few instances, of fresh-water shells in all of the basin west of the eastern border of the basin of Lake Ontario. To the eastward of Lake Ontario, however, in the St. Lawrence and Champlain valleys, marine fossils are common in deposits supposed to be contemporaneous with the stratified clays to the west.

A careful search in the clays and beaches left by the former water bodies might be rewarded by important discoveries. In this examination microscopical organisms should not be neglected. If after a detailed examination no fossils are dis-

covered, this negative evidence would have its value, as it would indicate that the physical conditions were not favorable to life, and an explanation for this fact might be found. It is scarcely necessary to mention that care should be taken not to mistake the shells occurring in modern swamp deposits associated with the ancient beaches for true lacustral fossils.

About the borders of the present lakes and sometimes even below the level of the lowest of the ancient beaches the remains of the mastodon, elephant, giant beaver, elk, bison, deer, etc., have been found. The recency of the existence of such of these animals as are extinct may thus be established, as well as the former distribution of those still living in other regions.

Evidence of the existence of man has been reported from one of the old lake ridges in New York, and it is important that this interesting discovery should be sustained by evidence from other localities. Stone implements especially should be looked for in undisturbed lacustral clays, and in the gravels of the ancient beaches.

The remains of forests have been stated to occur in the lacustral clays adjacent to the south shore of Lake Erie. It is desirable to know the extent of these deposits and how continuous they are; also the character of the plant remains they contain, and whether they have been disturbed from the position in which they grew. Some of the questions that may be asked in this connection are: Was the basin drained and forest covered before the vegetable remains were buried, or were the plants floated to their present position, or did they grow on moraines covering the stagnant border of the retreating glacier and become involved and buried in morainal material as the ice melted?

6. *Life in the present lakes.*—The fauna of the present lakes has a bearing on their past history, for the reason that in the deeper parts of lakes Superior and Michigan crustaceans and fishes have been found which are believed to be identical with marine forms. These may be considered as "living fossils," and are thought by some to indicate that the lakes in which they occur were formerly in direct communication with the ocean. If

the occurrence of living marine species in the present lakes is found to be widely at variance with the history of the basin as determined from physical evidence, an inquiry should be made in reference to the manner in which the species discovered might migrate.

7. *Changes in elevation.* One of the most difficult problems in connection with the history of an inland region is the determination of changes of level. By leveling along an ancient beach, post-lacustral changes in the relative elevations of various points may be readily ascertained. Pre-lacustral changes, however, by which ancient valleys have been obstructed, are much more difficult of direct observation, but might appear from the study of the hard-rock topography, as has already been suggested. This branch of the investigation, however, should more properly begin at the coast and be extended inland.

8. *Former outlets.* Several localities where the waters of the Laurentian basin have overflowed during former high-water stages have been pointed out, but some confusion has arisen in this connection, for the reason that the channels formed by streams issuing from the margin of the ice during the closing stages of the Glacial epoch have, in some instances, been mistaken for evidence of former lake outlets. The old outlets which seem to have been well determined are situated at different levels, and show that the entire basin could not have been occupied by a single great water-body, unless, as has been supposed by some, it was in direct communication with the sea. This hypothesis will be considered below. It has sometimes been assumed that all of the basin below the level of some ancient outlet was once flooded, so as to form a great lake in all of the basin now situated at a lower level; but, in making such generalizations, the possibility of places in the rim of the basin being at a lower level than the outlet discovered, thus necessitating a special explanation, such as the partial occupation of the basin by glacial ice, or changes in elevation of such a character as to raise the locality of former overflow or to depress other regions, have to be considered.

Former outlets should bear a definite relation to neighboring shore lines and to sedimentary deposits. The channels leading from former points of discharge merit examination, as here again changes of level may perhaps be detected in the gradients of stream terraces.

Most of the ancient outlets thus far recognized lead southward, but as previously mentioned, a former channel of discharge north of Lake Superior has recently been reported. If this observation is confirmed, it will have an important bearing on questions relating to changes of level and to the position of the ice front during the later stages in the retreat of the glaciers.

9. *Probable effects of a retreating ice sheet on drainage.* The generally accepted conclusion that glaciers advanced southward and occupied the Laurentian basin during the Glacial epoch and retreated northward toward the close of that epoch, is sustained by a vast body of evidence. As the ice sheet withdrew it left a superficial deposit frequently one or two hundred feet thick over nearly all of the region it abandoned, and pre-glacial drainage lines were obstructed and mostly obliterated. As long as the slope in front of the ice was southward, the drainage from it found ready means of escape, but when the slope was northward towards the ice front, the drainage was obstructed and lakes were formed.

We have good reasons for believing that the topography of the Laurentian region was essentially the same at the close of the Glacial epoch as it is now, but the broader question of continental elevation is less definite. The inequalities of the surface being essentially as we now find them, it would follow that the first lake formed when the ice retreated to the north of the divide running through central Ohio and central New York, would be small and dependent on minor features in the relief of the land, and would discharge southward. As the ice retreated, the lakes would expand and become united one with another and the larger lakes thus formed would still find outlet across the southern rim of the basin. As the glaciers continued to retreat lower and lower, passes would become free of ice and the lakes

would be drained at lower levels, old beaches would be abandoned, the lakes would contract, and finally separate lakes would be formed in the lowest depression in the basins of the more ancient water bodies. The shape of the retreating ice front would be determined by topographic conditions and would in turn determine the northern outline of the lakes along its margin. This in brief is one hypothesis that has been proposed to explain the varied history recorded by the shore records, sediments, etc., within the basin.

10. *Communication with the sea.* Another hypothesis which assumes to account for some of the facts observed, is that the continent was depressed at the close of the Glacial epoch sufficiently to allow the sea to have access to the Laurentian basin. This hypothesis is coupled with others which do not recognize a period of Pleistocene glaciation, but, as already suggested, this is a matter that is considered by the great body of American geologists as not being any longer open to profitable discussion.

In the study here outlined the question whether the water bodies which formerly occupied the Laurentain basin were lakes or arms of the sea, should not be difficult of direct and positive determination. If fossils can be found within the basin, they might yield definite testimony, but even if they are absent or if their evidence is inconclusive, topography can be appealed to with the expectation of receiving a conclusive decision.

If the Laurentian basin was occupied by an arm of the sea during various stages in the Pleistocene elevation, then the records of such a submergence should occur both within and without the depression, and direct connection between the two should be expected. If the waters within the basin were capable of making such well-defined shore records as are now found, we are justified in assuming that the true ocean beach on the outer slopes of the basin would be still more conspicuous. Again, the waters within the basin deposited a sheet of sediment, certainly not less than one hundred feet thick; to be sure the conditions for rapid accumulation were there present, but if the ocean covered the adjacent land it should have left similar de-

posits. This is abundantly proven in the St. Lawrence and Champlain valleys, where clays containing marine fossils occur up to a certain horizon and record a Pleistocene invasion of these depressions by the sea. If the adjacent Ontario basin was occupied by the sea about the same time that the Champlain valley received its filling of c'ays containing marine fossils, there is every reason to believe that the deposits and their contained fossils in each basin would have been essentially the same.

One of the best known of the ancient shore lines about Lake Ontario has an average elevation of approximately 500 feet above the sea. If the sea had access to the basin at the time this breech was formed, then at corresponding horizon without the basin especially, to the south and southeast, where the full force of the Atlantic's waves would have been felt, there should be still more prominent beaches.

Many well-defined shore lines in the Laurentian basin are much higher than the one just referred to, and if these were also formed during various stages of submergence, as has been claimed, it is evident that ocean beaches and ocean sediments of Pleistocene age should be looked for over nearly the whole of the eastern part of the United States. The student may easily answer this question for himself, and thus perhaps make a contribution to the subject here treated.

In the investigation here outlined, the work of previous observers should not be ignored, and every plausable hypothesis that has been advanced to account for the facts observed should be carefully tested. In writing these pages I have not quoted the writing of others, for the reason that a discussion of evidence has not been the aim in view, and also because the writings examined are so numerous that justice could not be done them in the space at command. That the literature relating to the subject is voluminous is indicated by the fact that an annotated bibliography of the Pleistocene history of the Laurentian basin, now in preparation, already contains over 200 entries of individual papers.

ISRAEL C. RUSSELL.

EDITORIALS.

THE Summer meeting of the Geological Society of America will be held at Madison, Wis., on August 15 and 16. The session of the American Association for the Advancement of Science will begin at the same place on the 17th of August and extend to the 23d. The Congress of Geologists, under the auspices of the Columbian Exposition, will begin at Chicago, on August 24, and continue its sessions so long as its work may require. Preliminary to this series of meetings, Professors M. E. Wadsworth and C. R. Van Hise will meet such geologists as care to visit the Lake Superior region at the Commercial Hotel, Iron Mountain, Mich., on the forenoon of August 7, and will act as guides during the week following. A carefully prepared scheme for the trip is announced, embracing visits to the leading points of interest in the Menominee, Marquette and Gogebic iron districts, and in the copper-bearing region of Keweenaw Point. Those who desire to participate in the excursion, or who wish information regarding it, should address Professor Van Hise, at Madison.

In connection with the meetings of the Geological Society and the American Association at Madison, there will be excursions to the Devil's Lake region, to the Dells of the Wisconsin, and to the driftless area, under the guidance of geologists personally familiar with the features of most special interest. The article of Professor Van Hise in this number is a timely presentation of some points of peculiar significance in the first named region, and will prove very serviceable to those who choose the excursion to that region.

It is proposed to hold the sessions of the Congress at Chicago at the Art Institute during the forenoons, leaving the afternoons free for visiting the Exposition. Experience has shown that a half day devoted to looking at exhibits, where there is

such a plethora of objects of interest as in the Exposition, taxes the faculties of observation to the full extent of their pleasureable employment. Attendance upon the Congress and the study of the Exposition will, therefore, it is thought, constitute agreeable and profitable complements of each other. Excursions to points of geological interest in the vicinity of Chicago will be privately arranged, if desired.

These three meetings, with the attending excursions and the study of the Exposition, constitute a rare combination of opportunities which will doubtless be embraced very generally by the geologists of the country. T. C. C.

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THE supply of numbers one and two of this JOURNAL remaining in the hands of the publishers has become reduced below the limit they desire to preserve for binding and for special purposes, and they would esteem it a great favor on the part of those who may have received duplicates, as sample copies or by the accidents of mailing while the lists were imperfect, if they would return such duplicates to them. They will gladly return the postage if the address of the sender is placed on the wrapper.

REVIEWS.

CRYSTALLINE ROCKS FROM THE ANDES.

Untersuchungen an altkrystallinen Schiefergesteinen aus dem Gebiete der argentinischen Republik von B. KÜHN. Neues Jahrbuch für Min., etc., Beit. Bd. VII., 1891, p. 295,

Untersuchung argentinischer Pegmatite, etc., von P. SABERSKY, *ib.* p. 359.

Untersuchungen an argentinischen Graniten, etc., von J. ROMBERG, *ib.*, VIII., 1892, p. 275.

TRAVELERS and foreign residents in South America are rapidly furnishing information relative, not only to the volcanic, but also to the older crystalline rocks composing the great Andes chain. Since the early observations of Darwin,[1] the petrographical collections made by Stelzner during his three years' residence, as professor, at Cordova (1873 – 1876) have been described by himself[2] and Franke,[3] while the results of detailed studies of the more extensive collections gathered by Stelzner's successor, Professor L. Brackebusch, are now beginning to appear. Professor Brackebusch's residence in the Argentine Republic lasted from 1876 till 1883, and during this period he made numerous scientific expeditions.[4] The petrographical material thus obtained has been confided to specialists in Germany for study. Three papers dealing with the crystalline schists (gneisses),[5] pegmatites,[6] and granites,[7] have recently appeared. The rocks of the granite contact-zones

[1] Geological Observations in South America, 1846.

[2] Beiträge zur Geologie und Paleontologie der argentinischen Republik; I. Geologischer Theil, 1885.

[3] Studien über Cordillerengesteine. Apolda, 1875.

[4] Reisen in den Cordilleren der argentinischen Republik, Verh. der Gesellsch. für Erdkunde. Berlin, 1891.

[5] Untersuchungen an altkrystallinen Schiefergestenien aus dem Gebiete der argentinischen Republik, von B. Kühn. Neues Jahrbuch für Min., etc., Beit. Bd. VII., 1891, p. 295.

[6] Untersuchung argentinischer Pegmatite, etc., von P. Sabersky, *ib*,, p. 359.

[7] Untersuchungen an argentinischen Graniten, etc., von J. Romberg, *ib.*, VIII., pp.

had been placed in Professor Lessen's hands before his death, while communications on other special groups are doubtless to be expected.

These investigations naturally suffer from the forced absence of all field observations on the part of their authors, but the purely petrographical study of the material brings to light many points of interest, while it furnishes the only sort of detailed information regarding the rocks of these remote regions which we can for the present hope for. It is here desired only to direct attention to a few of the most striking results obtained from the Brackebusch material by the three authors last cited.

Dr. Kühn's paper on the crystalline schists treats principally of gneiss, and offers little that is new. It is mostly occupied with additional evidence of structural and chemical changes due to dynamic metamorphism in the sense of Lehmann. The most noteworthy of these are development and microstructure of fibrolite; production of augen-gneiss from porphyritic granite; development of microcline structure in orthoclase by pressure; secondary origin of microcline, microperthite and micropegmatite; alteration of garnet to biotite and hornblende.

Dr. Sabersky's paper on the coarse-grained granites or pegmatites is entirely mineralogical, and is devoted principally to elucidating the structure of microcline. The author concludes that the well-known gridiron structure is due, not to two twinning laws (the Albite and Pericline), as has been generally supposed, but to the Albite law alone, in accordance with which the individuals form both contact and penetration twins, like the albite crystals form Roc-tourné, described by G. Rose.

Dr. Romberg's paper on the Argentine granites is much more extensive than the two preceding. It is embellished by seventy-two microphotographs, many of which admirably illustrate the special points described. He comes to several results of great petrographical significance, the most important of which relate to the origin of quartz-feldspar intergrowths in granitic rocks. He clearly shows that beside the original granite quartz there is also much of a secondary nature present. This is not microscopically distinguishable from the original mineral, but its later genesis is demonstrated by many careful observations on its relation to other constituents. The abundant secondary quartz is regarded as the product of weathering — principally of the feldspar, into which it has a peculiar tendency to penetrate. The

extreme sensitiveness of quartz to pressure is emphasized (as it has been by Lehmann and the present writer) and illustrated by undulatory extinction, banding, granulation and even plastic bending around other minerals. Dynamic action is regarded as the efficient cause of the secondary impregnation of feldspar by quartz, and a union of this with weathering of the feldspar as the source of the abundant and complex pegmatitic intergrowths of quartz and feldspar.

These results are important, and they will now doubtless come to be generally recognized. It is, however, of interest to observe in this connection that all which is here announced as new in regard to secondary and "corrosion" quartz was described and figured in even greater detail by Prof. R. D. Irving ten years ago. This does not appear to be known to Dr, Romberg, for he does not allude to it, but anyone who will turn to pages 99 to 124 and plates XIII, XIV and XV of the monograph on the Lake Superior Copper Rocks (vol. 5, U. S. Geol. Survey, Washington, 1883) will find his conclusions stated in almost the same language and with a much wider range of fact and illustration. Dynamic action is not here adduced as a cause for the saturation of feldspar by secondary micropegmatitic quartz, since the Lake Superior rocks show no evidence of having been subjected to pressure, but that the quartz itself has been derived from the leaching of the feldspar substance and that the impregnation is mostly confined to the orthoclase is clearly stated.

Dr. Romberg also demonstrates, in a number of cases, the secondary origin of albite, especially as microperthite, and of microline. He gives details relating to each of the mineral constituents, and then the effects of pressure and of chemical action on the most important of them. Among many interesting observations but a few can be even mentioned here; such, for instance, as the original character of muscovite in many granites; the alteration of garnet into muscovite; the dependence of the well-known pleochroic halos in biotite and cordierite upon the substance of the zircon which they almost invariably surround, and secondary rutile needles which grow out from biotite into both quartz and feldspar. In one rock occurring in a granite a violet, strongly pleochroic mineral was found, which, in neither composition nor physical properties, agreed exactly with any known species. It seems to be intermediate between andalusite and dumortierite, but, as its individuality is not yet perfectly established, no new name is proposed for it.

G. H. WILLIAMS.

The Mineral Industry, its Statistics, Technology and Trade, in the United States and Other Countries, from the Earliest Times to the End of 1892. Vol. I. Edited by RICHARD P. ROTHWELL, editor of the *Engineering and Mining Journal.* 629 pp., 8vo.

This volume is a statistical supplement of the *Engineering and Mining Journal*, and is published by the Scientific Publishing Co., of New York, 1893. It takes the place of the former annual statistical number of the *Engineering and Mining Journal*, and it is the first volume of a series which is to be issued annually. The object of the present volume is to make known, as soon as possible after the expiration of the year 1892, the statistics and the various conditions of the mining industry in that year and in previous years. The future volumes will, each year, bring these statistics up to date, and thus the full particulars of the mining industry will be known within a few days of the expiration of every year. The volume is a compilation of articles written by different authors, and the names of these writers are guarantee that the different subjects have been treated by authorities in the departments with which they deal. The editor himself, it is but justice to him to state, has written some of the most important parts of the volume, notably the article on the statistics of gold and silver, and his well-known familiarity with the subjects he discusses renders the reader confident of their accuracy.

The present volume is not confined to the bare presentation of figures of production and consumption of various mineral products, but it treats each individual branch of the mining industry in its various departments; and in this way the volume really represents a series of treatises on the various mining products and the methods of treating them. The production of each material is given not only for the United States but also for foreign countries; the conditions of the American and foreign markets during 1892 and previous years are discussed, while the various uses of the different materials, the history of mining in different districts, the means of transportation. the metallurgical methods of treating different ores, the methods of sampling, and the possibilities of competition in various mining industries are also described. In addition to this, tables of assessments levied and dividends paid by various mining companies are given. The volume ends with a concise statement of the statistics and condition, as well as the extent, of the mining industries of foreign countries. Thus there is presented, in a volume of no excessive size, a complete and concise

epitome of the mining industries of the world; and this work was completed almost immediately after the time to which it relates.

The various subjects are treated in the following order: A resumé and tables of statistics of the mineral products of the United States; articles on Aluminum, Antimony, Asbestos, Asphaltum, Barytes, Bauxite, Borax, Bromine, Cement, Chemical Industry, Chromium, Coal and Coke, Copper, Corundum and Emery, Cryolite, Feldspar, Fluorspar, Gold and Silver, Iron and Steel, Lead, Manganese, Mica, Nickel and Cobalt, Onyx, Petroleum, Phosphate Rock, Platinum Group of Metals, Plumbago, Precious Stones, Pyrites, Quicksilver, Salt, Soda, Sulphur, Talc, Tin, Whetstones and Novaculite, Zinc; Tables of Assessments Levied by Mining Companies from 1887 – 1893; Tables of Dividends Paid by American Mining Companies; Baltimore Mining Stock Market, Boston Mining Stock Market, Denver Mining Stock Market, London Mining Stock Market, Lake Superior Mining Stock Market, New York Mining Stock Market, Paris Mining Stock Market, Pittsburg Mining Stock Market, Salt Lake City Mining Stock Market in 1892, San Francisco Mining Stock Market; Foreign Countries — Austria-Hungary, Belgium, Canada, China, France, Germany, Italy, Japan, Russia, South American Countries, Spain and Cuba, Sweden, United Kingdom of Great Britain and Ireland.

The importance of the subject treated in this volume can be appreciated when it is known that the products of the mines of the United States alone in the census year of 1889 amounted to $587,230,662, and that this amount really only represents the interest on an immensely larger capital invested. The mining products of the United States are far more important in their aggregate value than those of any other country in the world, though, in many individual products, other countries supply more than the United States. This country is first, however, in the production of pig iron and steel. It is also first in the production of copper, gold, silver, petroleum, and a number of other products. Great Britain is still the leader in the production of coal, but the United States' production is rapidly growing and already equals 81.08 % of the British production, and supplies 28.75% of the world's consumption.

Every subject in this volume is fully discussed, and at the same time nothing is given which is not appropriate and even necessary. Thus a combination of completeness and conciseness is reached which is excellent. Among the most carefully and exhaustively treated subjects are

copper, gold and silver, the platinum group of metals and coal and iron, though many others might be mentioned, for every subject undertaken has been thoroughly treated. In the article on copper the statistics of production and consumption, as well as the condition of the various domestic and foreign markets, are fully discussed by the editor, and, in addition, separate articles are also given on "American Methods of Ore Sampling and Assaying," by Albert R. Ledoux, and on "Bessemerizing Copper Matte," by Charles Wade Stickney. The article on the statistics of gold and silver is by Mr. R. P. Rothwell, editor of the volume, and is an excellent piece of statistical work, giving, as it does, the statistics of production of gold and silver in the world for a number of years back. To this article are appended interesting papers on the "Chronology of the Gold and Silver Industry, 1492–1892," by Walker Renton Ingalls, on "Recent Improvements in Gold Chlorination," by John E. Rothwell, and on the "Cyanide Process," by Louis Janin, Jr.

The article on the Platinum Group of Metals, by Charles Bullman, gives complete information regarding the production, consumption, nature of the deposits, metallurgy and uses of platinum and its related metals, iridium, rhodium, osmium, palladium and ruthenium. The articles on Coal and Coke and on Iron and Steel, both by Mr. Wm. B. Phillips, give full statistics of production and consumption, as well as interesting historical data, and reports of the condition of various markets. Many of the other articles in this volume deserve mention, but lack of space forbids further detail. It may be said, however, that everything necessary is presented, and nothing unnecessary or unreliable is given; in other words, the volume contains no trash.

One of the most noticeable features of the volume is the uniform and systematic manner in which the results are presented. The uniform arrangement of statistics is a matter requiring the greatest labor and statistical ability. Compiling a single table of statistics is a simple matter, but arranging a vast mass of statistics, relating to many diverse subjects, on a uniform and intelligible basis, is entirely another matter, and requires the highest skill of the statistician. In the Mineral Industry this has been accomplished in a most successful manner; everything is clear and intelligible at the first glance, and everything is in its proper place. A great detriment to the systematic presentation of statistics has been, as pointed out by the editor, the necessity

of using our present system of weights and measures, with "our long and short tons, our barrels of 200, 280, 300 or 400 lbs, our pounds avoirdupois and our pounds Troy, our bushels of a dozen different weights, and our gallons of several incomprehensible kinds"; but the disadvantages of this system have been partly avoided in many cases by giving the statistics in metric measures as well as in our own.

The question of the cost of production has been given especial prominence in this volume, with a view to showing the reduction in the cost of the crude products. To use the words of the editor: "The itemization of cost is the first essential step in securing economy in producing any article, and the history of every country and of every industry has shown that prosperity, whether national, industrial, or individual, is, in a general way, inversely proportional to the cost of supplying the rest of the world with what one produces." These reductions are in no way dependent on the reduction of wages. On the contrary, many of the mining industries where the greatest reduction in cost of production has been accomplished, are carried on with high priced labor; and in many other cases, where the wages are not high, the condition of the wage-earners has been greatly improved. The reduction in cost of production has been entirely brought about by improvements in mining machinery, by a more thorough understanding of the nature of the deposits to be worked, and by more intelligent management and labor. The reduction in cost of production is nowhere better seen than in the materials most necessary to our welfare. For instance, coal can in some cases be carried by rail for 400 miles and delivered on board vessels for from $2 to $2.25 per ton, and yet the mine owners and railroads make dividends; some of the manufacturing establishments in Western Pennsylvania obtain coal at from 60 to 75 cents per ton at their works; hard gold-bearing quartz can be crushed, washed and 95 per cent. of the gold saved on the plates for $1.25 per ton; high grade Bessemer iron ore can be mined, handled, shipped and delivered a thousand miles from the point of production for less than $4.00 per ton. All these figures seem almost incredible until one investigates the various devices which the ingenuity and better education of those engaged in the industry have invented for reducing the expenses of production.

The former annual statistical numbers of the Engineering and Mining Journal were excellent in all they undertook, but the present

volume, the Mineral Industry, makes a great advance in giving the statistics for foreign countries in addition to those of the United States. By so doing it gives the American producers an opportunity to know the present, past and probable future conditions of competition in foreign countries.

The two most important features in any statistical work are accuracy and promptness. The necessity of accuracy is self-evident, and without promptness the statistics lose much of their serviceability to those most interested in them, for the statistics of an industry published a year or two years late are rarely of much value to those engaged in that industry. The business man wants his statistics immediately after the expiration of the time to which they relate, so that he may know the existing condition of the industry in which he is engaged; but if he does not get these statistics until many months or even several years afterwards, the condition of the industry may have changed entirely since the time to which the statistics refer. It is the promptness with which this volume is issued, combined with a high degree of accuracy, far greater than would be expected in statistics so hastily compiled, that gives it its especial value.

In conclusion, it may be said, that as a piece of statistical work, relating to an industry that is world-wide in its scope, combining accuracy with full detail and systematic arrangement, and issued so soon after the close of the time to which it relates, the Mineral Industry has never been equaled in this country or abroad. The former statistical numbers of the Engineering and Mining Journal, which referred mostly only to American mining, were considered remarkable pieces of statistical work, on account of the promptness of their publication; but in the Mineral Industry we have an epitome of the mining operations of every quarter of the globe, published almost immediately after the close of the time to which they refer, a feat which heretofore would have been declared impossible. This accomplishment is most creditable to the editor, Mr. Rothwell, to the systematic organization of the Scientific Publishing Co., and to the business manager, Mrs. Braeunlich, by whose business ability such an expensive undertaking is made commercially practicable. The volume will be found of the greatest value to the economic geologist, the miner, the engineer and the business man.

R. A. F. PENROSE, JR.

ANALYTICAL ABSTRACTS OF CURRENT LITERATURE.

A New Tæniopteroid Fern and its Allies. By DAVID WHITE. (Bulletin Geological Society of America, 4 pp., 119–122, pl. I.).

Mr. White has described, under the name of *Tæniopteris missouriensis*, a new and well characterized fern from the Lower Coal-measures in the vicinity of Clinton, Henry County, Missouri. Botanically, it is of particular interest in that it combines the so-called tæniopteroid and alethopteroid types of structure, while geologically it is of much value in supplying a readily identified stratigraphic mark in a part of the Carboniferous not especially rich in fossil plants. After thoroughly describing it and considering its specific and generic resemblances, the author discusses at length its suggested genetic relations and represents in a graphic manner a scheme of its probable ancestors and line of descent. F. H. K.

Rainfall Types of the United States. Annual Report by Vice-President GENERAL A. W. GREELY. (The National Geographic Magazine. Vol. V., April 29, 1893, pp. 45–58 pl. 20).

The paper confines itself to the characteristic distribution of precipitation throughout the year and gives the rainfall types of the country.

(a) The best defined type of rainfall within the United States is that which dominates the Pacific coast region as far east as western Utah. The characteristic features are a very heavy precipitation during midwinter, and an almost total absence of rain during the late summer. (b) The characteristics of the Mexican type, dominating Mexico, New Mexico and western Texas, are a very heavy precipitation after the summer solstice and a very dry period after the vernal equinox. August is the month of greatest rainfall, while February, March and April are almost free from precipitation. (c) The Missouri type covers the greatest area, dominating the watersheds of the Arkansas, Missouri and upper Mississippi rivers, and of lakes Ontario and Michigan. It is marked by a very light winter precipitation, followed in late spring and early summer by the major portion of the yearly rain; the period when it is most beneficial to the growing grain.

Abstracts in this number are prepared by F. H. Knowlton, Henry B. Kummel, J. A. Bownocker.

(d) The Tennessee type, prevailing in Kentucky, Tennessee, Arkansas, Mississippi and Alabama, has the highest rainfall the last of winter, while the minimum is in mid-autumn. (e) The Atlantic type, covering all the coast save New England, is one where the distribution throughout the year is nearly uniform, with a maximum precipitation after the summer solstice, and a minimum during mid-autumn. (f) The St. Lawrence type is characterized by scarcity during the spring months, heavy rainfall during the late summer and late autumn months, with a maximum during November.

The regions lying between these several type-regions have composite rainfall types, resulting from the influence of two or more simple types.

H. B. K.

The Geographic Development of the Eastern Part of the Mississippi Drainage System. By LEWIS G. WESTGATE, Middletown, Conn. (American Geologist, Vol. XI, April, 1893, 15 pp.)

The drainage of the Eastern Mississippi basin in post-carboniferous was in all probability consequent upon the tilting which accompanied the stronger folds of the Appalachian revolution in the east. The present drainage is found to accord in the main with this hypothetical post-carboniferous drainage, but several streams depart quite widely from it.

(a) The great drainage lines of the St. Lawrence basin are structural valleys developed along the strike of the softer Paleozoic strata, and at right angles to the original surface. The streams seem, therefore, to have adjusted themselves to the differences in hardness and structure of the beds discovered. (b) The Ohio and Cumberland rivers cut directly across the Tennessee and Cincinnati anticlines. The most probable explanation is that the rivers were superimposed upon the arched and eroded Silurian rocks from a thin cover of carboniferous beds — now entirely removed. (c) The Upper Mississippi does not follow the dip of the rocks to the southwest, but follows the strike to the southeast. This part of the river probably dates from the elevation of the plains on the west and the Appalachians on the east, which marked the close of the Cretaceous and which left a broad north and south valley. (d) The author finds good reason to believe that the Lower Mississippi, in post-carboniferous times, flowed west through Missouri and Arkansas. The present course was probably taken at the close of the Cretaceous in consequence of elevations on the west and east, and possible depression in the south.

The Cretaceous base-level recognized by Davis on the Atlantic slope can be traced more or less discontinuously, and remnants of it are believed to exist in Kentucky, Tennessee, Wisconsin, Minnesota and Arkansas. But in general the work of the Tertiary cycle has obliterated almost all evidence of it on all but the hard sandstones and conglomerates of the Paleozoic series.

Good examples of the lowlands excavated from the Cretaceous base-level during the Tertiary cycle, are the Valley of the East Tennessee and the central lowland of Kentucky and Tennessee. During the post-Tertiary sub-cycle the larger streams trenched to greater or less extent these lowlands. No attempt is made to carry the history of the development of the Mississippi drainage into the complicated chapter of the ice-invasion. H. B. K.

On a New Order of Gigantic Fossils. By ERWIN H. BARBOUR. (University Studies. Published by the University of Nebraska. Vol. I, No. 4, July, 1892, pp. 23, pl. 5).

A part of Sioux County, Nebraska, lying north of the Niobrara River, has yielded a new order of gigantic Miocene fossils unlike anything heretofore known. They are best described as fossil corkscrews, of great size, coiling in right-handed or left-handed curves about an actual axis or around an imaginary axis. The screws are often attached at the bottom to an immense transverse piece, rhizome, underground stem, or whatever it may be, which is sometimes three feet in diameter. In other cases the corkscrew ends abruptly downward, as it always does upwards. In still other cases the transverse piece is variously modified, and sometimes blends into the sandstone matrix, as if the underground stem, while growing at one end, was decaying at the other. The fossil corkscrew is invariably vertical, and the so-called rhizome invariably curves rapidly upwards, and extends outwards an indefinite distance.

That they could ever have been formed by burrowing animals, by geysers or springs, or by any mechanical means whatever, is entirely untenable. Their organic origin is unquestionable. Microscopic sections show smooth spindle-shaped rods, which are suggestive of sponge spicules. From the numbers seen in place it is evident that they flourished in thickly crowded forests of vast extent.

A finely preserved rodent's skeleton was found in one great stem. The probable explanation is not that the rodent burrowed there, but that its submerged skeleton became an anchorage for a living, growing Daimonelix, which eventually enveloped it.

The author proposes this provisional classification:

Order.	Family.	Genus.	Species.
	Daimonelicidæ.	Daimonelix.	circumaxilis
			bispiralis.
———	———	———	anaxilis
			robusta
		———	carinata.
		———	———
		———	———

The different species are described in full. H. B. K.

The Vertical Relief of the Globe. By HUGH ROBERT MILL, D.SC., F.R.S.E. Scottish Geographical Magazine, April, 1890.

The purpose of Dr. Mill's paper is to show a simple yet adequate basis on which to build the superstructure of physical geography. It does not attempt a discussion of the distribution and varieties of vertical relief. The structure of the earth is stated most simply by describing it as an irregular stony ball, covered with an ocean and an envelope of air. If the lithosphere were perfectly smooth and at rest, with the hydrosphere uniformly spread over its surface, the former would have the form of the terrestrial spheroid, and the latter would surround it to a depth of 1.7 miles. The surface of this hypothetical spheroid Dr. Mill calls *mean sphere level.* Of course, in reality the surface of the lithosphere is not perfectly smooth. Parts of it are greatly depressed and parts much elevated, the latter forming the land of the earth. The writer proceeds to calculate the position of mean sphere level, and in the absence of accurate data he uses the careful estimates of Dr. John Murray, which are as follows: Average depths of oceans = 2.36 miles; average height of land = .426 miles; average thickness of hydrosphere surrounding smoothed lithosphere = 1.7 mile; area of land = 55,000,000 square miles; area of oceans = 141,700,000 square miles. Suppose a block of 55,000,000 of square miles area and 1.7 miles deep to be cut out of the smoothed lithosphere and set down on the surface alongside the depression. No change will take place in the surface of the hydrosphere. If the surface of the 141,700,000 square miles of lithosphere were reduced to uniformity, the whole depressed area would lie .66 mile beneath mean sphere level, and the depth of the ocean becomes 2.36 miles. To raise the land to its actual mean level above the hydrosphere surface, a sufficient quantity of matter must be removed from the depressed area and placed on the elevated block. Let x = the thickness of the belt removed and y equal the thickness of the belt when placed on the elevated block. Then $x + y$ is the height of the land above the actual hydrosphere level. From the data given the following equations are easily obtained:

$$x + y - .426 = 0$$
$$141.7\,x - 55\,y = 0$$
$$x = .12 \text{ and } y = .306 \text{ in miles.}$$

The average height of the land above mean sphere level is thus $1.7 + .306 = 2.006$ miles, and the average depth of the depressed portion beneath mean sphere level is $.66 + .12 = .78$ mile.

Dr. Mill divides the earth into the three following divisions: (1) *Abysmal area,* occupying all the depressions beneath the mean surface of the lithosphere, occupying 50 per cent. of the earth's surface; (2) *Transitional area,* comprising all the regions above mean sphere level covered by the hydrosphere, occupying 22 per cent. of the surface; (3) *Continental area,* all the lithosphere that projects above the hydrosphere, or 28 per cent. of the earth's surface.

J. A. B.

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(*Further acknowledgments of pamphlets already received will be made in the next number.*)

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THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

Introduction.—Before the application of the microscope as a geological instrument the classification of rocks was dependent largely upon their apparent similarities and dissimilarities as noted by the unaided eye. When the use of this instrument became almost universal it was found that many rock types similar macroscopically were very different from each other in microscopic appearance, and very dissimilar genetically, while many of the apparently dissimilar types were discovered to owe their differences in appearance simply to the ordinary processes of weathering, which masked their original essential characteristics with the products of mineral alteration.

The rocks now known as gabbro are quite well characterized by peculiarities that are strikingly uniform in their essential features, though formerly the term was made to cover a large number of closely related but quite different rock types. Their history affords a good illustration of the manner in which rock classification developed from its early independent form to its present highly differentiated but well defined one.

In the case of the gabbros, as well as in the case of other rock groups, there were at first included under one name all rocks whose superficial features were similar to those of the type originally described. Later, more discriminating study separated this group into a large number of subordinate groups, based on

slight differences noted in the characteristics of their components. The number of such groups became larger and larger until eventually there were almost as many sub-groups recognized as there were students who had investigated them. Thus the classification grew complicated, because the criteria upon which it was based were mainly unessential, though prominent, peculiarities in the components comprising the classified bodies. The next step, following the use of the microscope in rock investigation, consisted in the consolidation of several sub-groups into one larger group—a result due directly to the comparative ease with which the microscope enables the student to distinguish between the primary and secondary—the essential and unessential—properties of rocks. After careful work of this kind had finally established the various varieties on the basis of mineralogical composition, attention was directed to the manner in which the rock components are associated—to the rock structure—and an explanation of variation in structure was sought in the environment of rock masses. The study ot the gabbros thus became a geological study rather than a mineralogical one.

The brief historical sketch of the classification of the granular basic rocks, with special reference to the differentiation of the gabbros from the remainder of the group, will thus serve to illustrate the successive steps with which rock classification in general has progressed. But the sketch is not offered here solely as an illustration of the development of rock classification. It was originally written with a view of emphasizing the distinctive differences between the gabbros and the coarse diabases. In the Lake Superior region there exist many coarse basic rocks that have been called indiscriminately "gabbros." Some of these possess the features of true gabbros, as defined by a study of the history of this group of rocks, and others the peculiarities of diabases. Until the distinction between these two types is clearly recognized, it will be impossible to discuss the causes of their differences. It is hoped that the present contribution will serve partly to clear the ground for a careful study of the coarse basic eruptive rocks of the Lake Superior

province, which the writer desires to make as opportunities and time permit. The present plan proposes a series of papers appearing in this Journal at irregular intervals. The first follows this introduction. The second will embrace a sketch of previous work on the basic rocks of the region, and the succeeding ones will treat of the gabbros and coarse diabases in the Huronian and Keweenawan areas on both sides of the lake.

I. BRIEF HISTORY OF THE CLASSIFICATION OF THE GABBROS AND NEARLY RELATED ROCKS.

At about the same time the names Euphotide and Gabbro were applied, respectively by Haüy[1] in France and von Buch[2] in Germany, to rocks composed essentially of a foliated augite and a "compact feldspar." Haüy describes the Euphotides as consisting of a compact feldspar and diallage, for which combination he constructed the name from the two Greek words εὖ (blessed) and φῶς (light), in allusion to the green and white mottling in the hand-specimens from many localities. Von Buch's name, gabbro, was adopted from the Florentines[3] to cover a group of rocks that had been described at various times under a great number of different names, of which perhaps jade was the most common. Although gabbro was used by the Italians to designate what is now known as a diallagic serpentine, it has been accepted by nearly all geologists outside of France as the name to be applied to the group of rocks which von Buch so clearly and definitely separated from other allied rocks, and defined as made up of jade, feldspar and smaragdite.

Between the time of the appearance of von Buch's paper and the publication of the first microscopic description of gabbros by Rose in 1867,[4] many descriptions of these rocks appeared in

[1] Traité de Mineralogie, 2d Ed., IV., p. 535.

[2] Ueber den Gabbro, mit einigen Bemerkungen über den Begriff einer Gebirgsart. Geol. natur. f. Freund. zu Berlin, Mag. etc., 1810, IV., p. 128; 1816, VII., p. 234.

[3] Cf. T. S. HUNT: Contributions to the History of Euphotide and Saussurite. Am. Jour. Sci., 2d Series, Vol. XXVII., 1859, p. 336.

[4] G. ROSE.—Ueber die Gabbroformation von Neurode in Schlesien. Erster Theil. Zeits. d. deuts. Geol. Ges. XIX., 1867, p. 270.

the various geological journals. In 1835 Gustav Rose[1] separated the rocks composed of labradorite and hypersthene, with accessory olivine, mica, apatite and ilmenite, from the gabbros, and included them under the name "Hypersthenfels," at the same time suggesting that the term gabbro be confined to rocks containing labradorite and diallage. Many rocks were described as hypersthenites or hypersthene rocks, because of the supposition that the highly foliated augite in them really belonged to this variety of pyroxene. Delesse[2] and others showed that the compact feldspar of Haüy, and the jade mentioned by von Buch as an essential constituent of gabbros (afterwards called saussurite by de Saussure Jr., and by Beudant) is in some cases a true plagioclase; and Hunt[3] showed that in other cases it consists of zoisite, of white garnet mixed with serpentine, or of meionite, and that the rocks containing these substances usually also contain hornblende, with the characteristics of Rose's uralite. Hunt, further, declines to regard the rocks containing a triclinic feldspar and pyroxene (either augite, hypersthene or diallage) as true gabbros. He places them among the dolerites, and declares that the true euphotides described by Haüy and de Saussure are mixtures of *smaragdite* and saussurite; a declaration that Cocchi[4] made for the Tuscan rocks a few years later. Rocks composed essentially of diallage and saussurite Cocchi called granitones. Whatever may be the virtue of the objections raised to the use of the name gabbro for plagioclase-diallage rocks, it still continued[5] to be applied to rocks thought to be of this composition, just as hypersthenfels or hypersthenite

[1] Ueber die Gebirgsarten, welche mit den Namen Grünstein und Grünsteinporphyr bezeichnet werden. Poggendorf's Annalen, XXXIV., 1835, p. 16.

[2] Recherches sur l' Euphotide. Bull. Soc. Géol. d. France, VI., 1848-49, p. 547.

[3] T. S. HUNT.—On Euphotide and Saussurite. Am. Jour. Sci., 2d Series, Vol. XXV., 1858, p. 437; and Contributions to the History of Euphotide and Saussurite. Ibid., XXVII., 1859, p. 326.

[4] I. COCCHI.—Description des roches ignées et sedimentaires de la Toscane dans leur succession géologique. Bull. Soc. Géol. d. France (2) XIII., 1856, p. 267.

[5] Cf. P. KEIBEL.—Analysen einiger Grünsteiner des Harzgebirges. Zeits. d. deutsch. geol. Ges. IX., 1857, p. 569.

was used to designate those in which hypersthene was supposed to occur.[1]

When Naumann[2] wrote the chapter on rocks for the second edition of his "Lehrbuch der Geognosie" he defined the gabbros as characterized by the possession of labradorite or saussurite and platy augite, and divided them into two varieties—the gabbros, consisting of labradorite or saussurite, diallage and smaragdite, and the hypersthenites, containing hypersthene as the pyroxenic constituent, and sometimes a little secondary hornblende. Naumann recognized the difficulty of distinguishing between the gabbros and the diabases, even at this early day, before it was known that augite could have imposed upon it a parting as the result of pressure, for he says "Diese Familie würde sich vielleicht mit der nächstfolgenden des Diabases vereinigen lassen" (p. 573); and again, in a foot-note to diabase "Wenn der feldspathige Bestandtheil der Gesteine dieser Familie wirklich in allen Fällen Labrador wäre, so würde es zweckmässig sein, die Familie des Gabbro mit ihr zu vereinigen" (p. 578): The norites described by Scheerer[3] and Esmark, were thought probably to belong with the gabbros, but their true relations to the group were not known.

A few years later Kjerulf[4] discussed the results reached by himself and other Norwegian geologists, and ended by dividing the Norwegian rocks of the gabbro type into gabbros and norites, the former consisting of labradorite, augite, hornblende, and the latter of labradorite and diallage.

[1] VON RATH: Geognostische Bemerkungen über das Berninagebirge (?) in Graubündten. Ib. IX., 1857, p. 246.

RAMMELSBERG: Bemerkungen über den Gabbro von der Baste (Radauthal im Harz). Ib. XI., 1859, p. 101.

VON RICHTHOFEN: Geognostische Bechreibung von Süd-Tyrol. 1860, p. 146.

[2] Lehrbuch der Geognosie. B. I. 1860, p. 573-577.

[3] Geognostisch-Mineralogische Skizzen, gesammelt auf eines Reise an der Südküste Norwegens. Neues Jahrb. f. Min., etc., 1862, p. 668.

[4] Zusammenstellung der bisherigen Ergebnisse der geologischen Untersuchung Norwegens. Neues Jahrb. f. Min., etc., 1862, p. 144.

The macroscopic examination of the rocks of this type continued to give rise to many different methods of classifying them, but the general tendency after this time seems to have been toward the union of the gabbros and the hypersthenites into one group. Von Cotta,[1] for instance, embraces the gabbros hypersthenites and norites under the single head "gabbro,"[2] and then divides this group into five sub-groups—gabbros (granitone of Cocchi and other Italians), with labradorite or saussurite and diallage, or saussurite and smaragdite (gabbro of Cocchi, Hunt and others); euphotides, equivalent to the saussuritized gabbros of later authors; norites of Scheerer, which are regarded as gabbros containing a soda-orthoclase and some quartz; hypersthenites, consisting of plagioclase and hypersthene, and finally, Monzoni-hypersthenites, afterwards discovered by de Lapparent[3] to belong to an entirely different group since they contain no hypersthene.

In the same year in which von Cotta's classification appeared Aug. Streng[4] began the task of reducing the number of varieties that had been separated as distinct sub-groups of the general group gabbro. In his article on the gabbros and associated rocks in the Harz he describes the former as made up of labradorite, diallage, hypersthene, augite, hornblende, brown mica, and ilmenite. Of the hornblendic constituent he says, it is " Kein selbständiger Gementheil des Gabbro, und es werden daher durch ihre Anwesenheit keine besonderen Abänderungen erzielt." It is fibrous and is intergrown with the augite and diallage. The labradorite is saussuritized (p. 935) and the saussurite is therefore regarded as an unessential component. The hornblende-gabbros and the saussurite gabbros of the Harz

[1] Die Gesteinslehre. 2, Aufl. Freiberg, 1862.

[2] Cf. also Rocks Classified and Described. A Treatise on Lithology. By Bernhard von Cotta. An English edition by P. H. Lawrence, London, 1866.

[3] DE LAPPARENT: Sur la constitution géologique du Tyrol meridional. Annales des Mines. (6) VI., 1864, p. 259.

[4] AUG. STRENG: Ueber Gabbro und den sogenannten Schillerfels der Harzes. Neues Jahrb. F. Min., etc. 1862, p. 932.

are nothing but altered forms of the fresh gabbro. It is rather surprising to one accustomed to the use of the microscope as a means of studying rocks to learn that such correct conclusions as to the inner constitution of rock masses could be reached without the aid of this instrument as were reached by Streng in his study of these rocks.[1] A few years later the same geologist examined the gabbros and serpentines of Neurode in Silesia and discovered that all of the so-called hypersthene of these rocks is probably diallage, and that the serpentine rock, which from very early times had been known under the name of forellenstein, is really an altered gabbro, containing but a small amount of pyroxene. While Streng was examining the rocks of Silesia and deciding that the so-called hypersthenite is a true gabbro, Des Cloizeaux,[2] was investigating the hypersthenites and gabbros of France, with a view to their better classification. Des Cloizeaux declared as the result of his investigations that diallage, which is only a lamellar augite, and saussurite form euphotides and gabbros, and that many rocks that had been called hypersthenites or hyperites contain no hypersthene, but that the supposed hypersthene is diallage. He further proposes that distinctions between gabbros and hypersthenites be made more clear by the use of the name diallagite for labradorite and diallage rocks, and hyperite for those composed of labrodorite and hypersthene or bronzite. Although the use of Des Cloizeaux's name diallagite was not accepted by petrographers, all workers acknowledged the correctness of the statement that very many of the hypersthenites described from various localities are nothing more than gabbro in which the cleavage of the diallage is well marked.

Thus far the study of the gabbros and related rocks had proceeded without the aid to be obtained from the microscope. Many rocks had been described as belonging to the gabbro-type,

[1] A. STRENG: Ueber den Serpentinfels und Gabbro von Neurode in Schlesien. Neues Jahrb. f. Min., etc., 1864, p. 257.

[2] ALF. DES CLOIZEAX: Sur les Classifications des roches dites hyperites et euphotides. Bull. Soc. Geol. d. Fr. XXI, 1864, p. 105.

as defined by von Buch, and these had been given distinct names in accordance with the usual custom of distinguishing between the different varieties of a rock containing different characteristic mineralogical components. The years between 1860 and 1862, perhaps, marked the height of the wave of differentiation. After this time the classification of the numerous varieties took the direction along which it was to be carried farther by microscopical methods. Some of the hornblende gabbros, the forellenstein, many of the hypersthenites and some of the norites had been shown to be altered or fresh forms of true gabbros. The characteristics of the components of the two groups of the gabbros and the hypersthenites had been fairly well determined, and the similarity between many of the gabbros and the diabases had been pointed out.

The best résumé of the state of knowledge at this time concerning the rocks under discussion is to be found in Zirkel's[1] "Lehrbuch," published a year before the microscope was brought into use for the purpose of studying these rocks. Zirkel collected the observations of the different workers and incorporated them along with his own in such a way as to give an excellent impression of the value of macroscopic rock determinations, when undertaken by competent observers and aided by chemical analyses. He distinguishes as gabbros those rocks containing labradorite and diallage, at the same time agreeing with Bischof[2] in the view that the latter mineral is merely a variety of augite. Saussurite he regards as sufficiently characteristic of some gabbros to warrant their separation from others. He likewise looked upon smaragdite, which was thought to be an intergrowth of augite and green hornblende, as an essential constituent of some gabbros, and these he separated from the diallage gabbros under the name of smaragdite gabbros. The hypersthenites are described at some length, with the appended statement that many hypersthenites are probably gabbros. The

[1] F. ZIRKEL: Lehrbuch der Petrographie. Bonn, 1866, p. 112.

[2] BISCHOF: Lehrbuch der chemischen und physkalischen Geologie. Bonn, 1864. 2 Aufl. II, p. 654.

norites of Scheerer are classed among the gabbros and the hypersthenites, and those of Esmark are said to belong partly with these and partly with the diorites.

In the year succeeding the appearance of Zirkel's book, as has been stated, Rose[1] made the first microscopical examination of gabbros that has been recorded. He found among the Silesian gabbros two varieties, one of which is black and contains olivine, and the other green and free from olivine. Tschermak[2] followed Rose with a description of some Austrian gabbros, and an announcement that many serpentines are altered gabbros, and that Streng's forellenstein is only an olivine gabbro. He concluded, further, that augite and diallage differ only in physical properties, and therefore that gabbro "ist eine Abtheilung des Diabas" (p. 168).

In the few years succeding Tschermak's paper several contributions of great importance were added to the literature of the gabbros. Zirkel[3] recognized olivine varieties of these rocks among the Tertiary formations on the islands off the west coast of Scotland, and succeeded in showing that the hypersthenites described by Macculloch from the island of Skye contain no hyphersthene. He further pointed out as important the fact that the plagioclase associated with diallage is rich in inclusions, while that associated with ordinary augite is free from them. In the same year Hagge[4] continued the work that had been so ably begun by DesCloizeaux in 1864. He made a careful microscopic examination of all the important gabbro and hyphersthenite occurrences recorded, and reached a result very similar to that of Des Cloizeaux. He found that very many of the rocks

[1] G. ROSE: Ueber die Gabbroformation von Neurode in Schlesien, Erster, Theil. Zeits. d. deutsch. geol. Gessel. XIX, 1867, p. 270.

[2] Die Porphyrgesteine Oesterreichs aus der mittleren geologischen Epoche. Wien, 1869.

[3] F. ZIRKEL: Geologische Skizzen von den Westküste Schottland. Zeits. d. deutsch. geol. Gessell. XXIII, 1871, pp. 58 and 92.

[4] R. HAGGE: Mikroskopische Untersuchungen uber Gabbro und verwandte Gesteine. Kiel, 1871.

heretofore described as containing hypersthene, have none of this mineral in their composition. He divided the gabbros into those containing olivine and those without this constituent, and from the latter separated a group which he called saussurite gabbros, recognizing at the same time, however, that saussurite is an alteration product of labradorite. He described it as consisting "of small crystal needles, prisms and grains, which are colorless or light-green, and are scattered irregularly in a ground mass with the appearance of a colorless glass, which often forms clear patches in the saussurite" (p. 52).

Six years after Rose's description of the Neurode gabbro, and seven years after the appearance of Zirkel's masterly classification of rocks based almost entirely upon their macroscopic properties, the latter geologist was enabled to issue a second volume containing a classification of rocks based on the microscopical characters. In this volume[1] he defines the gabbros as granitic in structure, and consisting principally of plagioclase and diallage, usually with the addition of olivine. The plagioclase is usually labradorite. It usually contains fluid inclusions and numerous little dark needles and prisms arranged in a definite order. The diallage is filled with small brown plates and the olivine is characterized by thousands of fantastically shaped hair-like bodies. The structure of genuine gabbros is described as coarsely or finely granular. They contain no porphyritic crystals and no unindividualized ground mass.

The group of hyphersthenites had by this time become almost depleted of its members. Most of the hyphersthenites had been found to be diallagites, in the sense of Des Cloizeaux, so that but four undoubted occurrences of this rock were left to be included by Zirkel in the group. On the other hand, the number of "forellensteins" had increased to such a degree that a group was formed of the same classificatory value as that of the hypersthenite group. These rocks were described as having the structure of gabbros, while at the same time they contain but

[1] F. ZIRKEL: Mikroscopische Beschaffenheit der Mineralien und Gesteine. Leipzig, 1873.

little diallage. Their separation from the gabbros and the hypersthenites seems to be upon mineralogical grounds solely; since emphasis is laid upon the fact that their feldspar is apparently anorthite. Of such great importance was the mineral constitution of rocks regarded at this time, that we find no statement made with respect to the similarity between many diabases and many gabbros. The facts pointed out by earlier investigators to the effect that augite and diallage are but slightly different varieties of the same mineral, had been overlooked, or had, at any rate, been regarded as of little importance, since these expressions of opinion had for the most part not been founded on the study of thin sections. The microscope was used principally for the determination of the nature of the constituents of rocks, and had therefore emphasized their mineralogical composition out of due proportion to its importance.

The influence of Zirkel's book upon geologists in all parts of Europe was soon felt in the increased number of purely petrographical papers published in the journals; and this increased interest soon manifested itself in studies that included more than a mere description of rock sections. Vogelsang[1] had, years before, shown that there were great possibilities in the new science of petrography, but in the flush of excitement over the discovery of an easy and exact method of rock analysis, these possibilities were left unexplored until geologists became quite well acquainted with the essential components of the most important rock types.

Soon after the composition of the important rock types became fixed, attention was turned more particularly to their structure. Professor Judd[2] examined the gabbros in the denuded cores of Tertiary volcanoes in Scotland, and found that while diallage is the prominent pyroxene of the lower portions of the

[1] H. VOGELSANG: Philosophie der Geologie und Mikroskopische Gesteinsstudien. Bonn. 1867.

[2] J. W. JUDD: The Secondary Rocks of Scotland. Second Paper. On the Ancient Volcanoes of the Highlands and the Relations of their Products to the Mesozoic Strata. Quart. Jour. Geol. Soc., XXX. 1874, p. 220.

masses, in their upper portions the diallage is replaced in large part by augite. Many other papers of importance were published, and in most of these the structure of the rocks described was more or less briefly alluded to. Wiik[1] announced the fact that many of the Finnish rocks classed by Zirkel among the hypersthenites are olivine-diabases and olivine gabbros, while Stelzner[2] filled the gap thus produced in this group by the discovery of a bronzite gabbro from the Monte Rosa district in the north of Italy. Vallee-Poussin and Renard[3] made a thorough examination of the plutonic rocks of Belgium and the eastern part of France, and discussed the composition and structure of some gabbros.

The result of these and other workers were collected and edited by Rosenbusch[4] in his well-known book on the microscopical characters of massive rocks, in which the fixing of rock types which had been begun by Zirkel was carried out in a scheme which was not improved upon until the same author published the second edition of his treatise ten years later[5]. In the scheme proposed in 1877, the gabbros were placed among the pre-Tertiary massive granular rocks. The group was made to include all pre-Tertiary rocks consisting essentially of diallage and plagioclase in their unaltered state, either with or without olivine. Saussurite was recognized as a secondary product produced by the alteration of plagioclase, and green hornblende (actinolite and smaragdite) as the result of an alteration of diallage. The saussurite and the hornblende gabbros were no longer

[1] F. J. WIIK: Mineralogiska och petaografiska meddelanden. Ref. Neues Jahrb. f. Min., etc., 1876, p. 206.

[2] A. STELZNER: Briefliche Mittheilung. Zeitz. d. d. geo. Gessell., XXVIII. 1876, p. 623.

[3] Ch. de la VALLEE-POUSSIN, et A. RENARD: Memoire sur les caracteres mineralogiques et stratigraphiques des roches dites plutoniennes de la Belgique et de l' Ardenne francaise. Bruxelles, 1876, pp. 62–76 and 125–128.

[4] H. ROSENBUSCH: Mikroskopische Beschaffenheit der Massigen Gesteine. Stuttgart, 1877.

[5] H. ROSENBUSCH: Mikroskopische Beschaffenheit der Massigen Gesteine. 2te Aufl. Stuttgart, 1887.

regarded as sub-groups of the gabbro family, but were looked upon merely as altered gabbros. Magnetite and titanic iron oxide as well as apatite were mentioned as accessory in all members of the group, and hornblende, rhombic pyroxene, brown mica and quartz were spoken of as occurring in many (p. 459). The difficulty of distinguishing between a gabbro and a diabase was clearly appreciated. The distinction between diallage and augite, upon which is based the mineralogical distinction between gabbro and diabase, is acknowledged to be of doubtful value for this purpose, since some rocks with the other properties of gabbros have an augite devoid of the diallagic parting, while others with many of the properties of diabase possess an augitic constituent with the parting highly developed. "Höchstens dürfen sie (the gabbros) als ein unterabtheilung der Diabase, welche sich durch eine eigenthümliche Structur und Theilbarkeit ihres Pyroxens charakterisirem." The structure of the gabbros was said to vary within narrow limits. They are always coarse-grained rocks whose different structures depend principally upon the different amounts of their constituents. Since they are so well characterized by the monotony of their texture, and since no gradations[1] between them and porphyritic or glassy forms were known, while on the other hand the structure of the diabases varies so widely between holocrystalline and glassy, the former were regarded as a distinct rock type. Rosenbusch, however, declined to regard the gabbros as dependent for their individuality upon the mere possession of an augite with pinacoidal parting, but was inclined to look upon them as rocks occupying a position in the scheme of classification intermediate between that of the diabases and that of the norites, the latter

[1] MR. T. T. GROOM has recently described a gabbro glass associated with gabbro at Carrock Hill in the Lake District, England, under the name carrockite. Since this glass occurs only as a narrow selvage where the gabbro has cooled rapidly in contact with preëxisting rocks, it cannot be considered as contradicting the above general statement. The structure is not one connected genetically with the rock itself, but is a local phenomenon dependent upon extraneous circumstances. See T. T. Groom: On the Occurrence of a new form of Tachylyte in Association with the Gabbro of Carrock Fell, in the Lake District. Geol. Magazine. Jan. 1859, p. 43.

consisting of plagioclase and an orthorhombic pyroxene, and therefore corresponding in part to Zirkel's hyphersthenites. The principal difference between the gabbros and diabase was, then, one of structure, while subordinate to this was a difference in mineralogical composition. In his sentences closing the discussion of the gabbros Rosenbusch writes: "Man müsste aber alsdann das Hauptgewicht für die Absonderung der Gabbros nicht auf den eigenthümlich struirten Diallag legen, sondern darauf, dass sie einen pinakoidal spaltbaren klinorhombischen Pyroxen als wesentlichen und daneben einen rhombischen Pyroxen als accessorischen Gemengtheil enthielten." The distinction here made is evidently a strained one, for quite a number of gabbros were known in which the structure is the typical gabbro structure, while at the same time they are entirely free from rhombic pyroxenes. The new group name "Norites" is borrowed from Esmark and Scheerer, although the rocks described by these geologists are by no means typical of the group. The advantage of the name over "hyphersthenite" is readily appreciated when it is remembered that the rhombic pyroxene of these rocks is not always hyphersthene.

The publication of Rosenbusch's classification of the massive rocks fixed the characteristics of the various types with some degree of scientific accuracy. There was, however, much to be learned concerning the less well known types, and much more to be discovered concerning the relations of the various types to each other.

The work of Judd, referred to above, was the beginning of a severe attack on the wavering line of geologists who still clung to the belief that mineralogical differences alone should determine the class to which a rock should be referred. It would be unprofitable in the present place to mention all of the important articles treating of gabbros and their varieties. It will be sufficient for our purposes to refer briefly only to those papers in which new types of gabbro are described and a little more fully to those which treat of the classification of these rocks.

The existence of true hyphersthenites (norites), of gabbros,

and of types intermediate between these, was established at the time that Rosenbusch's book appeared. In this year (1877) Törnebohm[1] suggested that the name hyperite be used for the latter classs, composed essentially of plagioclase, diallage and an orthorhombic pyroxene, that the term gabbro should be used to designate plutonic rocks in which the pyroxene is diallage, and that hyphersthenite (or norite) should be restricted to those containing a rhombic pyroxene as their principal augitic constituent. This suggestion has not met with a very wide acceptance because the gradation between the three types is very gradual, and in all cases the geological relations of the types are the same. It is convenient, however, as a descriptive name for those gabbros containing two pyroxenes.

In the same year Streng[2] investigated the crystalline rocks of Minnesota and described a gabbro from near Duluth, in that State, to which he gave the name hornblende-gabbro, because of the supposition that the brown hornblende it contains is primary. Irving,[3] however, has shown that much of the brown hornblende in the rocks of the Lake Superior region is secondary. He thought that nearly all, if not all, of the hornblende of the hornblende gabbros is of this nature. Williams[4] has also shown that compact brown hornblende is often a secondary product of the alteration of augite; and Wadsworth[5] holds to the view that this is the character of all the hornblende in the Lake Superior gabbros.

[1] A. E. Törneböhm: Ueber die wichtigsten Diabas und Gabbrogesteine Schweden. Neues Jahrb. f. Min., etc., 1877, p. 387.

[2] A. Streng and J. H. Kloos: Ueber die krystallinischen Gesteine von Minnesota in Nord Amerika. Neues Jahrb. f. Min., etc., 1877.

[3] R. D. Irving: On the Paramorphic Origin of the Hornblende of the Crystalline Rocks of the Northwestern States. Am. Jour. Sci., Vol. XXVI, 1883, p. 27; Ib. XXVII, 1884, p. 130.

[4] G. H. Williams: On the Paramorphosis of pyroxene to hornblende in Rocks. Am. Jour. Sci., XXVIII, 1884, p. 259.

[5] M. E. Wadsworth: Preliminary Description of the Peridotytes, Gabbros, Diabases and Andesytes of Minnesota. Bull. No. 2. Geol. and Nat. Hist. Surv. of Minn., St. Paul, 1887, p. 66.

If Irving, Williams, and Wadsworth are correct in their opinion, the hornblende-gabbro of Streng is merely an altered form of gabbro, and therefore it does not deserve a distinctive name (except for the mere purpose of description), any more than do the saussurite-gabbros.

Another type of gabbro to which a distinctive name has been given is also found in the region surrounding Lake Superior. This is an orthoclase-gabbro which has been carefully described by Professor Irving. An unstriated feldspar taken to be orthoclase had been discovered in gabbros from European localities by various petrographers, but it was usually present in such small quantity that but little importance was attached to it. In this country Pumpelly[1] and Julien[2] identified orthoclase in certain gabbros from Wisconsin, and Irving[3] discovered it in similar rocks from both Wisconsin and Minnesota. The latter author describes the orthoclase as often reddened and charged with secondary quartz. He mentions in detail the characteristics of the rocks containing it, and regards the differences noted between these and the non-orthoclastic gabbros as of sufficient importance to warrant their separation from the latter under the variety name orthoclase-gabbro.

Within the past few months still an additional gabbro variety has been brought into prominence by Adams[4] and by Lawson[5] working in different portions of North America. This consists essentially of plagioclase with gabbro characteristics, with which is associated only now and then a grain of pyroxene or magnetite. It differs from "forellenstein" in containing no olivine, and from

[1] R. PUMPELLY: Geology of Wisconsin, III, 1880, pp. 38, 40, 41.

[2] A. A. JULIEN: Microscopical Examination of eleven rocks from Ashland County, Wisconsin. Geol. of Wisconsin, III, 1880, p. 233.

[3] R. D. IRVING: The Copper-Bearing Rocks of Lake Superior. U. S. Geol. Survey, Monograph V, pp. 50–56.

[4] F. D. ADAMS: Ueber das Norian oder ober-Laurentian von Canada. Neues. Jahrb. f. Min., etc. B.B. VIII, p. 419.

[5] A. C. LAWSON: The Anorthosytes of the Minnesota Coast of Lake Superior. Geol. and Nat. Hist. Surv. of Minn. Bull. No. 8, p. 1.

gabbro proper in the absence of diallage and orthorhombic pyroxenes. To this variety belong the norite[1] of New York State, the labradorite rock of Labrador, and the "anorthite rock" of Irving[2] from the north shore of Lake Superior.

But if we are to regard the anorthosites as gabbros in which pyroxene and olivine are wanting, we must pass to the other end of the series and include in the gabbro group those rocks in which plagioclase is wanting, and in which the sole essential components are pyroxene and olivine, or the pyroxenes alone—the peridotites of most authors and the pyroxenites of Williams.[3] Judd[4] has shown conclusively that the peridotites of Scotland are but phases of the gabbro with which they are associated, consequently they may with good reason be included within the gabbro group. But other peridotites and many of the pyroxenites must be regarded as distinct rocks. They are the products of the cooling of magmas of an essentially different composition from that of the gabbros, hence their consideration may well be excluded from this history.

The varieties of gabbro that depend upon mineralogical com position, so far as known, have been carefully described and named by their investigators—the names referring for the most part to the nature of their iron-bearing constituents. These are gabbro and olivine-gabbro, hyperite, norite, peridotite and pyroxenite, together with the alteration products of the first named, viz.: hornblende, saussurite, orthoclase, and perhaps quartz-gabbro,[5] the latter of which is more properly a quartz norite, since it contains no diallage. The varieties whose names have reference to

[1] Cf. F. D. ADAMS: l. c., p. 475 and 483.

[2] R. D. IRVING: Copper-Bearing Rocks of Lake Superior. Mon. V. U. S. Geol. Survey, p. 438.

[3] G. H. WILLIAMS: The non-Feldspathic Intrusive Rocks of Maryland and the course of their Alteration. Amer. Geologist, VI, 1890, p. 95. Not the pyroxenites of the French authors, which are mainly augite gneisses or schistose gabbros.

[4] J. W. JUDD: On the Tertiary and older Peridotites of Scotland. Quar. Jour. Geol. Soc., XLI, 1885, p. 357.

[5] Cf. U. S. GRANT: Note on the Quartz-Bearing Gabbroin Maryland. Johns Hopkins Univ. Circ. No. 103.

the feldspathic component are the orthoclase-gabbro of Irving and the eukrites[1] of the older authors. The latter name was proposed to designate rocks whose feldspar is anorthite. It never received a very wide application owing partly to the difficulty of distinguishing positively anorthite from the other plagioclases. Since the discovery by Tschermak that the plagioclases form a series of isomorphous compounds, the value of the distinction recognized by the name has disappeared and the name itself has fallen into disuse.

In addition to these there are two other varieties that seem to be sufficiently well characterized to deserve special names. One of these, the anorthosite, consists exclusively of gabbroitic plagioclase and the other "forellenstein" contains olivine and plagioclase.

During the past few years nearly all the work on the gabbros has tended toward the separation of these rocks from the diabases by sharper lines than those based merely on mineralogical distinctions. All those who had attempted to separate the two groups by the methods in use had failed, and some had thought it well to include the two in one group. The views of the earlier petrographers on this subject have been referred to. Later petrographers have accorded with these in their recognition of the fact that the value of the pinacoidal parting of diallage is not of great importance for the purpose of rock classification. The discovery of Judd, referred to above, produced a marked effect on the work of those who followed him in the same field.

In 1883 J. Roth[2] declared that the position of the gabbros with respect to the diabases depends upon the signification given to diallage. If we regard it as an altered augite with a pinacoidal parting produced by twinning it is found, as Rosenbusch has already stated, that the parting may occur in the pyroxene of some rocks without the presence of

[1] For a discussion of the eukrites see J. ROTH: Allgemeine und Chemische Geology, II, 1883, p. 200.

[2] Allegemeine und Chemische Geologie, II, p. 185.

twinning lamellae. On the other hand, the pinacoidal parting is entirely absent in cases where twinning lamellae are present. Consequently not much dependence can be placed upon this constituent as a means of distinguishing between gabbros and diabases. The former rocks are evidently related to the latter, whose typically granular, holocrystalline forms they are. Irving,[1] in his work on the geology of the Keweenawan series in Michigan, Wisconsin, and Minnesota, was compelled to make use of coarseness of grain as a means of distinguishing between diabases and gabbros, both of which were thought by him to occur as flows. "It is evident," he writes, "that my observations on these north Wisconsin gabbros bear out the conclusions reached by certain European lithologists, as to the subordinate importance of the foliated condition of augite, by which gabbro is ordinarily separated from diabase, of which it would seem to be merely a phase. Nevertheless, the name is here retained, not only because most of our rock is very close to the typical European gabbros, but more especially because it is so sharply contrasted with the typical Keweenawan diabase that a separate name seems necessary." And again, when speaking of the diabases, he says,[2] "Although grading through coarser kinds into the coarse olivine-gabbros, the fine-grained rocks here considered deserve a place by themselves. The gradation into the coarser kinds has never been observed in any one bed, and they are very strongly marked by their external characteristics, both in the fresh and altered states."

The prime distinction between the two classes of rocks is, then, one based upon structure and not upon the difference between the augitic and diallagic nature of its pyroxenic constituent. The structure of the most typical gabbros was recognized by most geologists to be granitic and that of the diabases as ophitic. Professor Judd[3] proposed to restrict the name

[1] Geology of Wisconsin, III, 1880, p. 171.

[2] Copper-Bearing Rocks of Lake Superior, p. 69.

[3] J. W. JUDD: On the Tertiary and older Peridotites of Scotland. Quart. Jour. Geol. Soc., Vol. XLI, 1885, p. 354; and On the Gabbros, Dolerites and Basalts of Tertiary age in Scotland and Ireland. Ib. XLII, 1886, p. 49.

gabbro to granitic forms of plagioclase pyroxene rocks, and to designate as diabases the ophitic, porphyritic and glassy forms. He agrees with Zirkel[1] and Lasaulx[2] in regarding the Hebridean rocks as Tertiary in age, and at the same time as corresponding in all their characteristic features with older augite-plagioclase rocks of granitic structure. These rocks possess not only the structure of the most typical gabbros, but their various constituents are marked by the same microstructure. The plagioclase, olivine, and augite contain the numerous inclusions that were so early recognized as characteristic of these minerals in gabbro, and the latter mineral, the augite, is marked by the diallagic parting, which is the result of the action of a secondary process upon ordinary augite. The process, called by Professor Judd[3] schillerization, is moreover shown to be a function of the depth at which the original rock magma cooled, and the granitic structure of the rock mass is demonstrated to be likewise due to the fact that the rock possessing this structure crystallized at some depth below the earth's surface.

The work of Professor Judd established two great facts, viz.: first, that the age of a rock cannot serve as a basis for rock classification, since it has but little to do with the development of a characteristic structure; and, second, that the geological position of a rock mass is the condition determining not only its structure, but also the peculiar features possessed by its constituents. The rocks which it is proposed to call gabbros are marked by both of the characteristics of deep-seated rocks, while the diabases possess neither of them. The differences between the two groups of rocks, as expressed by their structures, are probably differences that are dependent upon the geological conditions under which they solidified.

[1] Zeits. d. deutsch. Geol. Gesell. XXIII, 1871, pp. 58 and 93.

[2] Min. u. Petrog. Mitth. I, 1878, p. 426.

[3] Cf. also J. W. JUDD: On the Relations between the Solution-planes of Crystals and those of Secondary Twinning; and on the Mode of Development of Negative Crystals along the former. A Contribution to the Theory of Schillerization. Mineralog. Magazine, VII, p. 81.

Professor Rosenbusch[1] clearly appreciated the value of the work on the basic rocks of the Hebrides, for, in the second edition of his Mikroskopische Physiographie, he defines the gabbros as hypidiomorphically granular *plutonic* rocks, consisting of a basic plagioclase, diallage, or a pyroxene resembling diallage, rhombic pyroxenes and often olivine. The important feature in this definition is the characterization of the gabbros as plutonic rocks. The diallage no longer defines the gabbro. The conditions which determined the characteristic structure of the rock at the same time produced the diallagic structure in its pyroxenic constituent. The structure of the typical gabbros, as defined by Rosenbusch, is granular, with the components all equidimensional. Notwithstanding the fact that some plutonic rocks of this class seem to lack the granitic structure, it remains true that the typical gabbro is well described by this definition.

When, however, we seek to separate the gabbros from the diabases we are met at the outset with the same difficulties that have always stood in the way of an exact separation of these two rocks. Rosenbusch[2] describes the diabases as possessing some of the features of plutonic rocks, while at the same time they possess other features that are eminently characteristic of rocks that have flowed out upon the surface of the earth. He nevertheless includes them with the plutonic rocks, stating, however, at the same time that they occur principally as dykes and interbedded flows; are more frequently interstratified with schists than are any other plutonic rocks; and that their predominant structure is the ophitic. That there is a fundamental difference between the two rocks is shown by the fact that the typicial gabbro can not be traced into porphyritic or hyprocrystalline varieties, nor is it ever accompanied by tufas. Whereas the diabases are often porphyritic, and are not infrequently associated with diabasic tufas. A consideration of these phenomena, together with the great differences in the structures of the typical gabbros and diabases, have led Loewinson-Lessing to regard the gabbros as

[1] Mikroskopische Physiographie, der Massigen Gesteine, 2, Auf. 1887, p. 132.

[2] Mikroskopische Physiographie, 2 Auf. II, pp. 174 and 195.

the intrusive[1] equivalents of the diabases, which he thinks were effusive under water, with the augite porphyrites as their equivalent terrestrial effusives. The conclusions of Loewinson-Lessing are not at all startling in their originality, for the wide separation in origin of the two groups of rocks here discussed has been suspected by petrographers ever since the classification of rock-types based on age, mineralogical composition and structure, gave way to the classification founded on geological relationships. The placing of the diabases with the effusive rocks will probably be looked upon with favor by all petrographers, especially since Professor Rosenbusch[2] has treated of them as members of this group in his Heidelberg Lectures, and Brauns[3] has shown that a typical lava flow of a suitable composition may have the diabasic structure developed in it but a few feet below its upper surface.

Lawson,[4] on the other hand, has shown conclusively that the coarse grained, ophitic diabases, interbedded with the Huronian slates and quartzites on the north shore of Lake Superior, are not effusive, but are intrusive, and that their intrusion between the fragmentals with which they are associated, must have occurred at a time when these were deeply buried under a great thickness of overlying rocks. Consequently these coarse, holocrystalline diabases must be regarded as intermediate in their geological relationships, as they are in their structural features between the hypidiomorphic, holocrystalline, plutonic gabbros, and the typically ophitic, hypocrystalline effusive diabases.

But if the hypocrystalline diabases are classed with the effusives, their position with respect to the melaphyres and basalts

[1] F. LOEWINSON-LESSING: Quelques considerations genetiques sur les diabases, les gabbros et les diorites. Bull. d. l. Soc. Belge. de Geol. etc., II, 1888, p. 82.

[2] Cf. Zeits. d. deutsch. geol. Ges. XLI, 1890, p. 533.

[3] R. BRAUNS: Mineralien und Gesteine unf dem hessischem Hinterland II, 3, Diabas mit geflossener Oberflache (Strick oder Gekroselave) von Quotshausen. Zeits. d. deutsch. geol. Ges. XLI, 1890, p. 491.

[4] A. C. LAWSON: The Laccolitic sills of the northwest coast of Lake Superior, Geol. and Nat. Hist. Surv. of Minn. Bull. No. 8, 1893, p. 24.

must be defined. Brauns,[1] in the article referred to in the last footnote, has attempted this correlation. He finds, after reviewing the opinions of various writers on the subject, that "It is not possible to distinguish between diabase and melaphyre on purely petrographical grounds, whether olivine is considered as an essential component of melaphyres, as Rosenbusch holds, or whether it is regarded as unessential in these rocks." In order to construct an exact definition for these three types of rock Brauns is compelled to fall back upon distinctions of age, although Rosenbusch[2] in his last article, in which he refers to this subject, declares it as his opinion that "it requires no great foresight to prophesy that in the not very distant future, this separation [of the effusive rocks into an older and a younger series] will be proven untenable." In spite of the almost certainty that Braun's classification will meet with but little favorable acceptance, it is given here in order to complete the sketch of the history of gabbros and the related rocks. According to Brauns, the basalts are made to include rocks of this class from recent time to the beginning of the Tertiary age. The limit of separation between the melaphyres and the diabases passes through the productive coal measures; rocks older than this are regarded as diabases, while the melaphyres extend from the Carboniferous to the Tertiary. Each group is divided into varieties, according to structure, and into sub-varieties according to mineralogical composition. A tabular grouping of the principal divisions of the effusive rocks of the composition of diabase follows:

	Paleozoic to Productive Coal Measures.	Mesozoic to Tertiary.	Tertiary to Recent.
Granular - - -	Diabase.	Melaphyre.	Basalt.
Porphyritic - -	Diabase-porphyrite.	Melaphyre-porphyrite.	Basalt-porphyrite.
Glassy - - - -	Diabase-glass.	Melaphyre-glass.	Basalt-glass.

It is very evident that the introduction of the diabases among

[1] R. BRAUNS: Ib. 5. Systematik der Diabas, Melaphyr und Basaltgesteine. Ib. p. 532.

[2] H. ROSENBUSCH: Ueber die chemische Beziehungen der Eruptivgesteine. Min. u. Petrog. Mitth. XI, 1890, p. 146.

the effusive rocks has created a disturbance in the melaphyre-basalt group that can only be quieted by the ejection of one of the members of the group, probably the melaphyres, from the position it now occupies. When this is done it is probable that the diabases will take the position thus left vacant, and the plagioclase-augite rocks will be found to occupy these places with respect to each other: the gabbros, the position of a deep seated rock, the diabases that of the corresponding holocrystalline effusive, and the basalt that of the hypocrystalline equivalent.

W. S. BAYLEY.

WATERVILLE, ME., June 1, 1893.

NOTES ON THE STATE EXHIBITS IN THE MINES AND MINING BUILDING AT THE WORLD'S COLUMBIAN EXPOSITION, CHICAGO.

THE Mines and Mining Building at the World's Columbian Exposition contains exhibits of the different mining industries of the various states of the United States and of foreign countries, exhibits of many of the manufactured products derived from these industries, exhibits of various kinds of mining and engineering machinery, and many private mineralogical and petrographical collections of great value and interest. To describe the whole would require a volume, and it is the intention of the present paper to discuss only some of the more important features of the state exhibits, with occasional references to the foreign exhibits.

A mining exhibit should seek to show the actual resources of the region it represents, whether these resources be developed or undeveloped, and to give the different products prominence according to their present or prospective importance to the region. The products of present importance should be exhibited as showing what the region actually produces; the products of prospective importance should be exhibited as showing what the region contains in bountiful quantities, but what is not yet utilized, either from lack of knowledge on the part of the public concerning it, from temporary inaccessibility, or from some other cause. By this means many valuable materials, which have not yet been developed, are brought to the attention of the general public, and often to that of specialists on such subjects, and in this way receive quicker development than if they had not been exhibited. It is often difficult to give the proper relative importance in an exhibit to products actually being mined and those which have not yet been devel-

oped, but an effort can be made in this direction, and it is always possible to state that a given material is not being mined.

A properly arranged mining exhibit affords advantage in two directions. In the first place, it benefits the exhibitor in calling attention to his products, and in the second place it is of great educational benefit to the general public as showing what different regions produce. The best interests of the exhibitor are served by a true exhibition of his products; while the educational value of an exhibit depends almost entirely on the exactness with which the exhibit reproduces the actual state of affairs, for if the exhibit is exaggerated in one direction or neglected in another it leaves with the uninitiated a false idea of the resources of the region.

Most of the state exhibits have been collected and arranged by commissioners appointed by the state, and are supposed to fully represent the resources of the state. Many of the foreign exhibits, however, are made up of the individual exhibits of different mining companies, and often show only a certain class of the products of a given region. They are, therefore, not claimed to always represent the whole of the mining industries of a region[1] and cannot be criticised for not doing so. The state exhibits, however, should fairly and honestly represent the mining industry within their borders, giving undue prominence to no one product, and neglecting nothing that should be represented. In this feature some of the states have been highly successful, while others have done worse than make a failure, for they have misled those who are not sufficiently acquainted with the resources of the country to know that the exhibit is not characteristic. Some of the states have exhibited and made very prominent great amounts of materials which they do not possess in paying quantities; other states have actually exhibited materials which they do not possess at all, and which have been obtained from other states, a proceeding which is very misleading to the general public.

[1] A notable exception to this is the New South Wales exhibit, which is one of the best in the building.

It has been the object of Mr. F. J. V. Skiff, Chief of the Mines and Mining Building, to make the mining exhibit truly characteristic of the states and foreign countries represented, and thus to give it the greatest possible value to the general public and to the individual exhibitors. His supervision has been wise and systematic, and it is to him that a large part of the success of the mining exhibit is due. Where failures have been made they have been the fault, not of the Chief of the Mines and Mining Building, but of the commissioners under whose charge the exhibits were prepared, or else of the government of the state or country which they represent. Very often the commissioners have been so hampered by the fancies of the mine owners or others in their districts that, though entirely capable of doing so, they have been unable to make a creditable exhibit of the regions they represent. Many of the state exhibits contain a large amount of good and characteristic material which is often rendered useless and often ridiculous by bad and ignorant arrangement; while many otherwise good and characteristic exhibits are rendered very unattractive by the slovenly way in which they are exhibited and the untidiness of the cases and specimens. Of course the last mentioned defects are minor ones, especially to those interested in the subject; but at the same time the neatness of presentation has a great influence on the attractiveness, and hence on the benefits, of an exhibit to the general public. An exhibit which has no natural beauty may be made very attractive by neat and systematic arrangement, while on the other hand, an exhibit of beautiful things may be made actually repulsive by a slovenly and dirty mode of presentation.

The different state exhibits have been collected and displayed by means of the appropriations made by the various state legislatures for such work. As the amount and conditions of the appropriation varied very much in different states, the size and costliness of the exhibits vary accordingly, and often give a very great advantage to the state with the larger appropriation. In criticising an exhibit, therefore, these circumstances must be borne in mind.

Among the best American exhibits are, beginning with the Eastern states, those of Massachusetts, New York, Pennsylvania, North Carolina, Michigan, Minnesota, Missouri, Colorado, Montana, Arizona, Idaho and California; and in Canada those of the Provinces of Quebec and Ontario. Among the other foreign exhibits that of New South Wales is preëminent in the quality, nature and mode of arrangement of the exhibit. The exhibits of Great Britain, Germany, Norway, Sweden, Denmark, Spain, Greece, Austria, Switzerland, Belgium, Italy, South Africa, Ceylon, Japan, and other foreign countries, are good as far as they go.

Many of the mining exhibits of both states and foreign countries are divided, and put partly in the Mines and Mining Building and partly in the individual buildings of the states or countries in question. Such a course is a great mistake, as it renders the exhibit in both buildings imperfect, and those who see the exhibit in one building without knowing that it is supplemented in another, receive an incomplete, and therefore an erroneous, idea of the products of the country represented. Each mining exhibit should be kept together, whether it be in the Mines and Mining Building or in another building.

The exhibits of the New England states are naturally representative of less economic value than those of some of the other states, because, with the exception of building and ornamental stones, most of their mining products are of subordinate importance; but at the same time they display what they have in a systematic and consistent manner. The Massachusetts exhibit is thoroughly characteristic and well arranged, showing not only the economic products, but also many rocks and minerals of purely scientific interest. The Maine exhibit is also characteristic of the state, while the New Hampshire and Vermont exhibits are small but appropriate, consisting largely of building stones, with mica and other minerals from New Hampshire. The granite of New Hampshire and the granite and white marble of Vermont are displayed on a small but sufficient scale.

Coming westward, the New York exhibit is the first one we

find which is representative of great economic importance. It displays its clays, sands, iron ores, building stones, petroleum, salt, etc., in a thoroughly systematic and creditable manner, and gives a very good idea of the relative importance of the different products.

The Pennsylvania exhibit is somewhat more elaborate than that of New York, as it should be, on account of the greater value of its products. Its immense coal and oil resources, together with its iron, clays, glass-making materials, slates, building stones, etc., are very well displayed. A model showing the method of coal mining and relief maps of the anthracite basins and of the whole state add to the attractions of the exhibit. A large series of samples of crude and refined petroleum are an appropriate and interesting feature of the exhibit. A large column of anthracite in a conspicuous position in the centre of the building, and apart from the rest of the Pennsylvania exhibit, represents a vertical section of the "mammoth seam" on the property of the Lehigh Valley Coal Company. A second column, near the main Pennsylvania exhibit, is composed of blocks of the different products of that state, varying in size according to their importance, the smaller blocks being placed successively higher in the column.

New Jersey makes a much less elaborate exhibit than either New York or Pennsylvania, though it is neatly arranged and in some respects it is good. The magnetic iron ores of the northern part of the state, and the clays, marls, and other products are well exhibited. The zinc deposits of Sussex county, however, are only poorly represented, and in this respect the exhibit might have been improved. A glass-plate model of the zinc mines at Mine Hill, Franklin Furnace, Sussex county, is an attractive feature.

Virginia makes a very characteristic and well arranged exhibit, though the fact that the materials exhibited are not in cases detracts from their neatness. A large display of coal and coke, so rapidly becoming the most important products of the state, is made; while the characteristic brown hematite (limon-

ite), the manganese ores, zinc ores, clays, fire-brick, and slate of that state are represented. The Bertha Zinc and Mineral Company displays the zinc ores of the southwestern part of the state and the spelter made from them, as well as statues, wire, etc., made from the spelter.

West Virginia makes a fine display of coal and coke, at present two of its most important industries. Such an exhibit is very appropriate when we consider that forty-eight out of the fifty-two counties of the state are said to contain more or less coal. The salt, mineral waters, crude and refined oils, iron ores, and building stones are also displayed.

North Carolina makes a very neat and characteristic exhibit of iron ores, auriferous quartz, mica, kaolin, asbestos, building stones, gems, etc. The gems include diamond, sapphire, topaz, ruby, beryl, garnet, rutile, chalcedony, etc. A number of interesting models of gold nuggets are also displayed. A number of photographs of different districts form a part of the exhibit, which is neatly and systematically arranged.

South Carolina makes a good exhibit of its great phosphate industry, displaying the crude phosphate and also the manufactured superphosphate. The phosphate industry far eclipses in importance all other mining industries in that state, and the others, such as gold, iron, and manganese mining, in the western part of the state, are of very little and very unstable importance, and are not represented.

Florida, long unknown to the mining industry, has suddenly become of great importance on account of the recent discovery of its phosphate deposits. A small exhibit of these phosphates is made in the Mines and Mining Building, but it is not sufficiently extensive to do credit to a young and rapidly growing industry.

Louisiana makes a very appropriate exhibit of its mining products, among which are lignite, oils, salt, sulphur, marls, clays, chalk, building stones, grindstones, mineral waters, and other minor materials.

The Tennessee exhibit consists mostly of a "Mineral Exhibit

of Harriman, Tenn.," and shows the coal, coke, fossil and magnetic iron ores and brown sandstone produced in that district, together with the pig iron manufactured. The exhibit is creditable to Harriman, but it is a pity that the state of Tennessee in general did not make a full display of its coal, iron, marble, and many other mining resources. The Cleveland Fire Brick Company of Cleveland, Tenn., makes an exhibit of its clays and bricks.

Kentucky makes a good and extensive exhibit of coal and coke, with smaller collections of iron ores, building stones, clays, bricks, etc. A relief map of the state is also an attractive feature of the exhibit. The exhibit contains a large amount of good material, but it might be displayed to better advantage.

Ohio makes a good exhibit of coal, its most important mining industry, and also displays on a smaller scale its crude and refined oil, its salt, clays, iron ores, whetstones, etc. It presents a good model of a salt refining works, and makes a very attractive display of the bricks, tiles, etc., made from its clays.

Indiana makes a good business-like exhibit of just what it has and no more, including a display of coal, clays, building stones, oil, mineral waters, and tiles, and glass manufactured from native products. The exhibit is well arranged and shows all that is necessary.

Illinois makes an extensive display of its clays and the various manufactured articles made from them. A much more extensive mining, mineralogical, and geological exhibit of the state is made in the large state building elsewhere on the World's Fair grounds. This exhibit is well arranged, and truly indicative of the products of the state.

Michigan makes one of the most elaborate exhibits of all the states. The three great mining products of this state are iron, copper, and salt. The first two are excellently represented; the last is much neglected. The different kinds of iron ore are illustrated with numerous specimens; and a large colored cross-section of the Cleveland Cliffs Iron Company's mine is given. A wooden model of the No. 4 Ore Dock at Marquette,

on the Duluth, South Shore and Atlantic Railroad, gives a good idea of the method employed in handling large quantities of ore. The different modes of occurrence of the copper of Michigan are shown by a number of well selected specimens; while the copper in ingots, sheets and wire is well displayed. Interesting wooden models are given of the shaft house and mills of the Calumet and Hecla mine, and of the rock and shaft house of the Tamarack mine. Other interesting features of the exhibit are a number of pre-historic copper implements from Michigan, and arches and columns of brown sandstone produced in the state.

The Wisconsin exhibit contains some good material, but it seems to be arranged more to give prominence to fine specimens than to show systematically the products of the state. The lead and zinc industries of the southwestern part of the state are well represented, but the great iron interests of the northern part of the state are neglected, one pile of ore indefinitely marked "iron ore" and a few other odd specimens being all that are displayed. Some good specimens of granite and columns of red sandstone are also exhibited. In addition, various mineral specimens are displayed, some of which have come from other localities than Wisconsin, and are therefore misleading to the uninitiated.

Minnesota confines its exhibit almost entirely to its greatest mining industry, *i. e.*, the iron of the northern part of the state, and in this department the exhibit is very good. Some building stones and a few mineral specimens are also displayed. A wooden model of the Chandler mine, and a number of maps showing the mines and the geology of the state also form a part of the exhibit.

Iowa makes a small but fairly characteristic exhibit, consisting mostly of coal, building stones, etc. A feature of the exhibit is an artificial "drift" in a coal mine, showing the mode of working and transporting coal on underground tramways. A model of a coal shaft and breaker is also given.

The Missouri exhibit is excellently arranged, and is thoroughly indicative of the resources of the state. The lead, zinc and iron industries are well represented, and pig lead and

zinc spelter are displayed with the ores from which they are derived. A model of the dressing works of the Saint Joseph Lead Company and a relief map of Iron Mountain, colored to show its geology, are interesting features of the exhibit. The coal industry of the state is also represented, together with a number of building stones, ochres, etc., and a fine collection of calcite and other mineral specimens from the lead and zinc mines.

The South Dakota exhibit consists largely of tin ore, auriferous quartz, mica and some argentiferous galena, and is essentially a Black Hills exhibit. "Lode" tin ore and stream tin, as well as pig tin manufactured from the ores, are exhibited in large quantities. A large column of tin ore, from the property of the Harney Peak Consolidated Tin Company, contains a placard stating that the capital invested is $3,500,000, a fact it is difficult to understand they should wish to make so prominent in view of the unproductive history of their operations. The auriferous quartz is a good exhibit and characteristic of the quartz deposits of the Black Hills. Some beautiful pieces of Arizona silicified wood, which were polished in Dakota, are exhibited, but in lack of the proper explanation as to their source, they are misleading, as they suggest Dakota as the region from which they were derived.

Kansas makes a very good exhibit of lead and zinc ores with the pig lead and zinc spelter derived from them. The exhibit also includes a display of rock salt, gypsum, building stones and other minor products. The exhibit is small, but it is characteristic of the state and is well arranged.

Montana makes a good exhibit as far as it goes, but many localities and many important deposits are not represented. The best exhibits are from the great mining camp of the state, *i. e.*, Butte City. The great copper and silver interests of this district—especially the former—are well presented, and large quantities of sulphide copper ores, and the metallic copper made from them, are displayed. A quantity of gold quartz, and an interesting collection of gold nuggets are also a part of this exhibit.

The most prominent feature of the exhibit, however, is a solid silver, life-size statue of the celebrated actress, Ada Rehan, standing on a globe which in turn rests on a base of solid gold. The whole work represents several hundred thousand dollars worth of precious metals, all the products of Montana mines.

Wyoming makes a neat and effective exhibit. It consists largely of coal in columns and blocks, jars of petroleum, blocks of sulphate of soda and sulphate of magnesia, "lode" tin ore and stream tin ore from the northeastern part of the state, adjoining the Dakota tin region, iron ore, copper ore, auriferous quartz, lead carbonate, asbestos, agates, clay, sulphur, building stones, etc.

Colorado makes a fairly good display of its silver-lead ores, copper ores, gold ores, coal and manufactured lead and copper. Some of the building stones and iron ores of the state are shown, but these materials are not fully represented. An instructive feature of the exhibit is a series of cases of gold nuggets, dust gold and sheet gold from Breckenridge, Colorado. Many of the important mining camps in the state are represented, especially Aspen, Leadville, Creede, Cripple Creek, etc. The exhibit is fairly good, but a state of such immense mining wealth as Colorado could have made a much better one.

The Utah exhibit contains a large amount of valuable material, but it is too much crowded and badly arranged. The desire for a display of brilliantly contrasted colors has in some cases entirely upset the systematic arrangement of the exhibit, and has given part of it the appearance of the toy boxes with pieces of minerals glued on the outside that are sold to confiding tourists in our western states as works of art and value. The exhibit represents the varied mining industries of the territory, among the most important substances being coal, gilsonite, albertite, elaterite, asphalt, oil shales, sulphur, salt, iron ores, copper ores, silver and gold ores, building stones, etc. The exhibit of articles "japanned" by the gilsonite varnish are of interest. Some large specimens of silver-lead ores and ores containing chloride of silver are characteristic of the mines producing them.

The New Mexico exhibit contains some good material, but is not very well exhibited. The silver ores, one of the most important products of the territory, are well represented, being grouped according to the localities from which they came. A small cabin in the centre of the exhibit is composed of silver, lead and gold ores from different localities. A stuffed burro carrying a prospector's camping outfit is a somewhat sensational feature of the exhibit. A column of coal from Blossburg and Los Cerillos represents the growing coal industry of the territory.

The Arizona exhibit is very good and well arranged. It is truly indicative of the products of the territory. The most important features of it are the copper ores, the silicified wood and the gold ores. The copper ores especially are well represented, and a beautiful column of green and blue carbonates of copper from Bisbee forms the most prominent feature of the exhibit. While in the Michigan exhibit we see only native copper, in the Montana exhibit only sulphides of copper, here in the Arizona exhibit we see mostly carbonates of copper with some silicate and oxide of copper. Thus in these three copper districts we have representatives of three great classes of copper ores. An interesting feature of the Arizona copper exhibit is a series of models showing the underground workings of the Copper Queen Consolidated Mining Company at Bisbee. The Old Dominion Copper Company whose mines are at Globe, Arizona, makes a very excellent exhibit of its ores and its copper ingots in a cabinet alongside the main Arizona exhibit. The gold ores of Arizona are well represented, and some of the silver ores are also shown, while the beautiful polished sections of the celebrated silicified wood of Arizona form an attractive and interesting feature of the exhibit. Some of the so-called "onyx" is also exhibited in polished slabs.

Nevada makes a fairly good exhibit of its mining products, mostly the silver ores abundant in this region, and the accompanying minerals. A "special exhibit" from Eureka, Nevada, contains a number of interesting specimens.

The Idaho exhibit is fairly good, but not thoroughly characteristic of the state. The most prominent features are the silver-lead ores from the northern part of the state, green copper carbonates, and a mineral water known as "Idanha" from Soda Springs. A number of photographs of different mining districts are of interest.

Washington makes a fairly good, but poorly arranged, exhibit of gold ores, silver ores and silver-lead ores, and a few other products. The coal resources of the state are entirely neglected, though they are well represented in the Washington state building. This separation of the mining products of a region, and their distribution partly in one building partly in another, is a great mistake, as it gives a person who sees only one of the exhibits an incomplete and therefore an erroneous idea of the resources of the state. The exhibit should be all in one or the other building.

Oregon makes a large exhibit of auriferous quartz and shows a very good working model of hydraulic mining. Some building stones are also represented. The exhibit is very good so far as it goes, but it does not do justice to the state, as many of its developed and undeveloped resources such as iron, coal, etc., are not represented.

California makes a good exhibit, and one characteristic of the resources of the state. It is very appropriately composed largely of gold ores and a display of the methods of gold mining. The auriferous quartz of the celebrated Grass Valley and other localities is well represented. An interesting feature is a wooden model by A. C. Hamilton showing a system of mine timbering. Stibnite from San Benito county and the metallic antimony derived from it are also represented. Among the other prominent features of the exhibit are iron ores, asphalt, oils, slate and a beautiful display of ornamental and building stones. The so-called "onyx" from San Luis Obispo county, and the colored marbles from Inyo County are exceedingly beautiful. The exhibit is entered through arches built of the various ornamental stones of the state, while blocks of rock containing the beauti-

ful rubidolite, or pink tourmaline, are displayed at the entrance. Elsewhere in the building is a fine and beautiful exhibition of the so-called "onyx" from New Pedrara, in Southern California.

Besides the California exhibit in the Mines and Mining Building, an interesting collection of the mining products of the state, especially gold ores and native gold, are contained in the California state building. Somewhat similar specimens, however, are in the Mines and Mining Building, so that the division of the collection in this case is not especially injurious.

Among the foreign collections, that of New South Wales stands preëminent. The great mining wealth of this province is exhibited in a very systematic and thorough manner, and an excellent idea is given of the resources of the region. There is no attempt at a display of a sensational character as is seen in some of the exhibits, but everything is shown in a plain business way, in large quantities and in properly selected samples. Among the most prominent features of the exhibit are its tin, gold, silver, lead, antimony, copper, iron, manganese, and chromium ores, its coal, graphite, building stones, etc. The ores exhibited are average samples such as are sold in the market, and therefore give a true idea of the deposits represented. In many cases, as in antimony, tin, etc., the metals are exhibited in blocks or pigs, with the ore from which they are derived. The ores of the great Broken Hill silver mine and the statistics of its production are of interest to those acquainted with this famous mine. The exhibit of the tin industry is of great interest as representing the development of this comparatively new tin region, which has only been much developed since 1872; while the coal exhibit shows not only the bituminous coal of the region, but also the kerosene shales, etc.

Among some of the other foreign exhibits those of the provinces of Ontario and Quebec are very good, showing as they do the various products of those provinces in a thorough and systematic order. The other provinces of Canada do not make such good exhibits. A collection of the rocks of Canada by the Geological Survey is of great interest. Mexico exhibits a great

amount of material, but it is so arranged that it loses much of the benefit that it might afford to the exhibitors and to the public. Brazil makes a fairly good exhibit, while Chile, Ecuador and other South American countries are also represented. The South Africa diamond exhibit is very interesting as showing the modé of occurrence, methods of mining and washing, and cutting the diamonds. The exhibits of Great Britain, Germany, Japan and other foreign countries are also of interest. La Societé "Le Nickel" of France makes a very interesting exhibit of its nickel ore in New Caledonia, the nickel derived from it, pictures of the mine and various other interesting features of the industry.

Many others of the numerous exhibits of American and foreign products in the Mines and Mining Building might be mentioned, but lack of space forbids further elaboration. The same cause makes it necessary to discuss in another article the extensive and excellent exhibition of the United States Survey in the Government Building.

R. A. F. PENROSE, JR.

THE LAS ANIMAS GLACIER.

One of the largest of the extinct glaciers of the Rocky Mountains was that which occupied the valley of the Las Animas river. This stream originates in the San Juan mountains in southwestern Colorado, and flows nearly south to its junction with the San Juan river in New Mexico. The San Juan mountains, with their outlying spur, the La Platas, are the first high mountains encountered by the moist winds from the direction of the Gulf of California on their way northeastward; and although so far south, this region has perhaps the heaviest snow fall in Colorado, as Frèmont found to his cost. His expedition up the Rio Grande attempted to penetrate the snowiest part of the mountains.

Silverton is situated about fifteen miles from the head of the valley, and Durango about sixty. About one mile north of Durango, near Animas City, two well defined morainal ridges extend across the valley of the Las Animas, and from thence a plain or series of terraces of water-washed morainal matter extends for several miles down the river. I have not explored far below Durango, and do not know the extreme limit of the ice. At Durango the ice rose to about the same height as the mesa lying east of the city, on which is the reservoir of the water-works, 300 or more feet above the valley terrace. This is proved by the fact that a thin sheet of morainal matter covers the slopes of the bluff and extends back for a short distance on top of the mesa (up to 100 feet); whereas, beyond that the top of the mesa is a base level of erosion in the sedimentary rock, with none of the far-traveled bowlders that abound in the moraine stuff. The glaciated bowlders are largely composed of rocks found only near the head of the valley, such as volcanic rocks, Archean schists and granites, Paleozoic quartzites, etc. Most of these must have traveled thirty to sixty miles.

About a mile above Durango, at the most distinct of the terminal moraines thus far noted, the valley widens to about one mile, and continues pretty broad for twelve miles or more northward. The valley is here covered with rather fine sediment. It is marked on Hayden's maps as alluvium, but the glacial character of the terraces near Durango is not recognized, though deposits substantially the same, situated a few miles northwest of Durango in the La Plata valley, are markedly morainal.

The post-glacial history of the valley was as follows. The terminal moraines near Durango formed a dam that held in a lake. This lake was partially filled with sediments, and at the same time the river was cutting down through the morainal barrier. The outlet is now so low as to drain the lake, except there are some low, marshy flats where the water stands only a short distance below the surface of the ground.

I have visited many of the tributary valleys of this river above Silverton. Every cirque had its glacier that flowed down into the larger valleys. The volcanic rocks of that region weather readily, so that one seldom finds glacial scratches except at recent excavations for roads and mines. It has therefore been a matter of considerable difficulty to determine the depth of the glacier of the main valley. By degrees the estimated depth increased until a few months ago, when I found scratches well preserved on quartzite at a height estimated at 1,500 feet above the Las Animas river. This was near the Mabel mine, about four miles southeast from Silverton, and not more than 500 to 800 feet below the top of the ridge which here borders the valley on the east. The glaciated rock is situated on a long gentle westward slope, while the scratches have a north and south direction. Local glaciers would have flowed westward. These scratches are therefore parallel with the movement in the main Las Animas valley, under conditions where no local glacier could have produced them.

It thus appears that near Silverton (elevation of valley about 9000 feet) the Las Animas glacier was 1,500 or more feet deep, while at Durango (elevation about 6000 feet) it had a thickness

of about 350 feet and a breadth of one-fourth mile or more. Its extreme length was more than sixty miles, probably about seventy miles. The average slope of the upper surface was eighty-three feet or more per mile. For fifteen miles its breadth was one or more miles.

From the terminal moraines near Durango, the valley of the Las Animas is for several miles southward covered by a plain of water-washed material, from coarse gravel up to bowlders three to five feet in diameter. Some of these have glacial scratches, though most have been so much rolled and polished as to preserve no distinct scratches. The lower terraces at Durango are of this character. They are typical of the overwash gravels found in many of the Rocky mountain valleys. The subglacial streams poured out their load of sediments in the valley in front of the ice, where they were mixed with some material dropped directly from the ice, and hence not rolled far enough to obliterate the glacial scratches. More or less of this glacial gravel is found in all the wider parts of this valley and its tributaries above Silverton until we reach within five or ten miles from the heads of the valleys. During the retreat of the tributary glaciers they poured out much less glacial gravel after they came to be ten miles or less in length, and what there was is usually but little water-worn.

Since the above was written further exploration reveals the fact that a large glacier originated on the eastern slopes of the La Plata mountains, and flowed southeastward down the valley of Junction creek and joined the Animas glacier in the northern part of Durango. Five hundred or more feet above the creek it left a lateral moraine on the top of the narrow ridge which borders the valley on the south. The moraine consists chiefly of the eruptives and metamorphosed sediments found in the La Platas, and but little of the local rocks.

The drift terraces near Durango are found at different levels. The lowest terrace is that above described, and consists of glacial gravel mixed with matter that has been but little rolled. The higher terraces have the appearance of ordinary valley terraces as seen from the river, but in some cases do not extend

back to the sides of the valley. The largest of these lies on the east side of the Animas river, between Animas City and Durango. It is more than a mile in length, and the outer or distal side ends in a bluff twenty to forty feet high. At its north and south ends this curved terrace approaches near to the mesa bordering the valley, thus enclosing a depression several hundred yards wide that is occupied by a small lake in time of violent rains. A basin of this kind could not have been hollowed out by the river, and, besides, the terminal moraines of Animas City extend across the north end of the basin. It is evident that this terrace was formed laterally to the glacier in substantially its present form. It contains great numbers of boulders up to fifteen feet in diameter, but a large portion of it has been very much water-rolled. The most probable interpretation is that these higher terraces began to be deposited at the outer edge as a lateral moraine. Then as the ice gradually receded morainal matter and glacial gravel were simultaneously deposited in the space between the moraine and the retreating ice. This hypothesis well accounts for the fact that morainal and water-rounded matter are so intimately mixed in the terrace, also that the overwash did not spread laterally back to the margin of the valley. We thus have the terraces ending distally in the steep slope characteristic of the moraine rather than the more gentle slope of the overwash apron. Most of these higher terraces end proximally (next the river) in rather steep slopes or bluffs rising twenty to seventy-five feet above the lower terraces. No city of Colorado has so much of glacial interest within its limits as Durango, unless it be Leadville.

It is an interesting fact that the cols of the mountain ridges of this region are glaciated almost or quite to their tops. Thus at Stoney Pass, the first pass north of Cunningham Pass, I saw well-glaciated rocks within 200 feet (horizontally) from the top of the pass. From the top of this pass the mountain slopes steeply northwestward toward the Las Animas valley, and in the opposite direction down the Rio Grande valley. The rocks at the summit were weathered, and it was not evident whether

the top of the ridge had been glaciated, but it is certain the ice or snow flowed in opposite directions from the col. On each side of the pass, peaks of the Continental Divide rise above the col to a height of 1000 to 2000 feet. It is evident that the snow from these peaks would flow or slide from each side down into the pass, and maintain a supply of névé or ice right on top of the ridge in the pass. The pass is about 11,800 feet high. It thus appears that the snow fields reached nearly to the tops of the mountains, say about 12,000 feet in the cirques and passes, while above this the discharge was probably in large part by avalanches.

Durango city is situated in about N. Lat. 37° 16′, a few miles north of the end of this glacier. It is to be carefully noted, in the study of the climates of the glacial epoch, that a glacier nearly seventy miles long reached so far south. Apparently the most snowy part of Colorado now was also the most snowy then.

During the retreat of this glacier it left numerous small retreatal moraines, both in the main valley and in the tributary valleys above Silverton. One of the most accessible is near the junction of the two branches of Mineral creek, about three miles northwest from Silverton.

It is noticeable that the proportion of moraine stuff left by this glacier is small as compared to the glacial sediments. Nowhere have I yet found very noticeable ridge or terrace lateral moraines. This is in part due to the steepness of the hills that border the sides of the Animas valley. There is usually a scattering of glaciated matter on these hill slopes, and where they are less steep, or in lee of ridges projecting out into the valley, local morainal sheets are sometimes found that have a depth of twenty feet or more. Small terrace-like lateral moraines extend for a mile or two north of the terminal moraines of Animas City near Durango. Probably the snow avalanches and flowing névé carried down débris and incorporated it with the glacier proper, so that there were no large surface lateral moraines as in some of the valleys of the Alps, or in the Arkansas and some other valleys of Colorado. In other words, the débris of this glacier was largely englacial and basal. GEORGE H. STONE.

STUDIES FOR STUDENTS.

CONDITIONS OF SEDIMENTARY DEPOSITION.

EROSION.

Erosion consists of fragmental reduction and abrasion of rock masses, chemical disintegration of rocks and transportation. The three sub-processes may be called rock-breaking, rock-decay and transportation. They are conditioned by declivity, lithologic character and climate.

ROCK-BREAKING.

Favorable conditions:

(*a*) Steep slopes.
(*b*) Bare rocks.
(*c*) Cleaved and jointed rocks.
(*d*) Alternation of hard and soft beds.
(*e*) Rapid changes of temperature.
(*f*) Aridity and high winds.
(*g*) Abundant rainfall, in the absence of vegetation.
(*h*) Sea cliffs.

Products: Shingle, gravel and sand of mixed mineralogical composition.

ROCK-DECAY.

Favorable conditions:

(*a*) Gentle slopes.
(*b*) Porous soil.
(*c*) Soluble rock constituents.
(*d*) Carbonic acid and other acids of organic decay.
(*e*) Abundant rainfall in the presence of vegetation.
(*f*) Prolonged transportation of gravel and sand.

Products: Rock cores of disintegrated masses, sand, (chiefly quartz-sand), residual clays, and lime, magnesia, iron, etc., in solution.

TRANSPORTATION.

Favorable conditions:

(*a*) Steep slopes.
(*b*) Abundant rainfall.
(*c*) Absence of vegetation.
(*d*) Floods
(*e*) Fine detritus.

By comparison of the statements of favorable conditions for rock-breaking, rock-decay and transportation it becomes apparent that breaking and decay are favored by opposite conditions in nearly all respects, while breaking and transportation are most efficient under like conditions. But breaking promotes decay, and decay aids transportation, by reducing the size of the particles to be decomposed and carried, and the maximum effect of erosion is probably attained when rock-breaking is active among greater elevations, and rock-decay and transportation are both proceeding energetically on lower slopes.[1]

The amount of material furnished by erosion is an important consideration in reference to the rate of accumulation of sediments over a given area, and is a condition not to be overlooked in comparing thicknesses of deposits with the lapse of geological ages.

SEQUENCE OF SEDIMENTS.

Shingle, gravel, sand, clay and silt are products of erosion of rock masses. They are produced either by mechanical breaking or by chemical disintegration. These two subprocesses of the general process of erosion are favored by unlike conditions. Those conditions which render breaking most efficient are unfavorable to immediate disintegration; and those conditions which promote disintegration limit breaking. Breaking, the reduction of a rock mass to small pieces, is usually

[1] Gilbert, Henry Mts. p. 105.

the antecedent of disintegration, of decay, but the two are not most efficiently active at the same time. Now their products differ. Rock breaking yields shingle, gravel, coarse sand of mixed mineralogical composition, and no chemical solutions. Rock-decay yields directly no shingle or gravel, but produces sand, chiefly quartz-sand, clay, silt and chemical solutions. Hence, if the products of rock-breaking are deposited unchanged in the sea, there will result one class of sediments from which we may infer corresponding conditions of erosion of the parent land; and if the products of rock-decay are deposited we must infer other conditions of erosion.

Declivity is the chief factor which determines either rock-breaking or rock decay. Rock breaking occurs on steep slopes, that is, among hills or mountains; rock-decay takes place chiefly on gentle slopes, that is, in valleys or on plains. Hence the sediments may indicate the topographic phase of the parent-land.

They may indicate topographic phase, not permanent topographic character, for relief of the land surface is transient. The steeps of mountains become the slopes of hills, the hill slopes sink to plains and plains to base-level; and erosion pauses till renewed by uplift. So the conditions of rock-breaking pass into those of rock-decay, and the product of the two processes may appear in sediments, the older gravel and sand beneath the younger sandy clay and clay.

The possible sequence of unlike sediments does not stop with the finer mechanical products of disintegration; chemical solutions may be related to chemical or organic deposits, and these have their place among strata. The amount of lime and magnesia carried annually from a given land area is directly related to the efficiency of rock-decay, and so among other factors to slope. Rock-decay is limited on the one hand by declivities, which promote the rapid running off of rainfall, and on the other hand by the accumulation of a deep covering of soil, which prevents percolation. Other things being equal, it is probably most efficient during the period corresponding with the life of low hills and sloping plains. If at any time chemical solutions from

the land determine the deposition of calcareous formations they will do so most efficiently during this topographic phase, and in the absence of mechanical sediments the corresponding deposits will be limestones or dolomites. As the topographic phase passes to its close and the sloping plains sink to base-level, the power of streams to transport mechanical sediment fails, and rivers finally carry only silt in lessening proportion; hence the upper portions of a great limestone deposit may be less clayey than the lower. Furthermore, the mantle of residual clays, accumulating upon the extended base-level, will check solution, and thus, in so far as the deposition of limestone is influenced by contributions from the land, will limit the growth of the formation; and with the cessation of both mechanical and chemical supply, terrigenous deposits will cease to form beneath the sea. Then, while these conditions endure geologic ages may pass without record in sediments unless there is a marine source of supply.

Thus far this statement has tacitly assumed a constant relation of elevation between coast and ocean. Assume that the long quiet, which has been necessary for the reduction of a mountain range to base-level and the deposition of the corresponding sediments, is interrupted by sinking or heaving of the land area. The surface is low, flat and covered by a mantle of residual sand and clay intimately mingled. Moderate subsidence must lead to extensive transgression and the invading sea, margined by tide flats, will spread arenaceous, clayey deposits, bearing the marks of shallow water formations and resting unconformably upon the ancient rocks. If the residual soil be red, the sediments will be of similar color, since the process of deposition on tide flats does not involve much attrition and the ferruginous coating of the grains will remain.[1] The base of the deposit may be a zone of transition, composed of cores of undecomposed rocks, imbedded in more or less re-arranged products of partial decomposition.[2]

[1] Bull. U. S. G. S. No. 52. I. C. Russell, Subaërial Decay of Rocks and Origin of Red Color of Certain Formations.

[2] R. Pumpelly. The Relation of Secular Rock Disintegration to Certain Transitional Schists. Bull. Geol. Soc. of America. Vol. [illegible]

Or, on the other hand, moderate uplift of the base-leveled continent, must cause the revived streams rapidly to sweep into the sea the mass of insoluble clay and sand which formed the residual mantle. Thus the limestone deposits will be succeeded by a thickness of shales of a more or less arenaceous or clayey character.

From these considerations it follows that a complete topographic cycle may be related to a sedimentary sequence composed of a sandy base, a limestone middle and a shale top. Newberry first noted the frequent recurrence of this sequence, and sought an explanation in conditions related simply to the sea; its advance, presence and retreat. When he made his generalization the base-level had not been recognized as a result of continued erosion, nor had Gilbert analyzed the process of erosion; and Davis had not described a topographic cycle. These contributions to the science have widened the field of inference, and the topographic phase of the land can no longer be disregarded in the discussion of the deposits of the sea.

But it should not be forgotten that the inference from sediments should be confined to the topographic phase of a belt of land extending back from the shore to a moderate distance only. The products of rock-breaking disintegrate during prolonged transportation and mountains remote from the coast are not indicated in deltas of great rivers. A student of the deposits of the Mississippi would not infer the height of the Rocky mountains, but the sands of the Klamath river bear witness to the nearness of the coast range.

The analysis and discussion of conditions which govern the character of the material contributed from land to sea might be extended in detail, and illustrated by descriptions of sediments in existing rivers, but the subject is worthy of independent treatment.

SEDIMENTATION.

Sedimentation consists of three sub-processes, sorting, distribution and deposition. These are effected by waves and undertow, tides, winds and oceanic currents and are modified

by the relation of volume of sediment to the force of waves or currents. If the analysis be based on the sub-processes and conditions which favor them, it may be stated and discussed as follows:

SORTING.

The conditions under which sorting is more or less efficiently carried on are three in number.

Favorable conditions:

(*a*) Vigorous wave action accompanied by strong undertow.

(*b*) Prolonged transportation in consequence of deep water and continuous currents.

(*c*) Moderate volume of sediments.

The conditions under which sorting is not accomplished are the reverse of these, namely:

Unfavorable conditions:

(*a*) Feeble or diffused wave action.

(*b*) Concentrated deposition.

(*c*) Excessive volume of sediments.

It will be profitable briefly to discuss these positive and negative conditions.

(*a*) *Vigorous wave-action.*—The force of waves is determined by their fetch and the strength of winds. In the study of modern beaches the latter is important, since it controls the form and the greatest storm[1] fixes the maximum size of detritus moved; but in considering fossil beaches as strata we deal with sands which have been so rearranged during submergence that the beach form is lost. However the former condition, the fetch of the waves is more constant, and the force of the waves determined by it may be inferred from the nature of the beach deposits.

The efficiency of waves of a given force is determined by the concentration of their blows, and this is conditioned by the slope against which they break. If relatively deep water prevails

[1] For full discussion of wave erosion and deposition, see Lake Bonneville, by G. K. Gilbert. Monograph 1, U. S. G. S.

to the shore, whatever force the waves may have is expended at the water's edge. On a bold coast they carve sea-cliffs and grind shingle with sand. Such are the coasts of New England, Oregon, California, and of all the Pacific side of South America. The resulting sediments are composed of worn but fresh rock fragments and thus bear witness to rapid mechanical erosion, like the products of rock breaking on steep declivities. On a shore of incoherent materials waves stir, wash and separate fine and coarse, light and heavy particles. Under favorable conditions of depth of water and long fetch, waves thus sort a heterogeneous mass of gravel or of residual sand and clay more efficiently than any other agent, and leave clean cross-stratified beach sand and gravel with boulders, while the finer materials are swept away. The southeastern shore of Long Island presents a conspicuous example of this, and the westward drift of the beach-sands is illustrated in the fact that shingle beaches prevail toward the eastern end of Montauk point, and the sands there washed from the bluffs of glacial gravel form long barriers along the coast to the westward.

If, on the other hand, waves break in shallow waters at a distance from shore they there build a barrier, and the height to which they build it above high tide is the measure of their maximum power during great storms. Within the barrier then extends a lagoon. The whole Atlantic coast from Long Island to Florida is thus fringed by the features of prevalent wave action, due to the great fetch from off the ocean and the gradual slope of the continental platform.

(*b*) *Prolonged transportation.*—Sorting is also accomplished to some extent, though less perfectly, by deep water and continuous currents. Sediments settle unequally according to size and specific gravity of particles; therefore the largest and heaviest reach bottom first, the finer and lighter later, and the finest and lightest last. If the conditions of supply or current be intermittent over any area then each incident of deposition will be marked by a layer composed of coarsest grains below and finest grains on top. This is the nature of deposition in tidal estua-

ries. If, on the other hand, currents be continuous and constant, the zones of sand, clay and silt deposits will occur each beyond the former. But this is a question of distribution as well as of sorting of sediments.

(*c*) *Moderate volumes of sediments.*—Sediments are also more or less completely sorted by waves or currents according to the relation between the volume of sediment and the force of the sorters. When waves breaking upon a coast have only the product of wave erosion to handle they sort most completely; the material is washed again and again until no trace of clay remains mingled with the sand grains; and the under-tow, burdened only with the clay washed out by the waves and the fine products of abrasion, carries them all away. But where a river pours out a large volume of sediment, and waves or currents are consequently overloaded, both sorting and transportation fail to a greater or less degree. Deposition takes place too rapidly for the separation of fine from coarse and the deposit is of mixed character. The effect of waves is then seen in ripple-marked and ill-assorted beds of tide flats.

DISTRIBUTION.

The conditions under which sediments are more or less widely distributed, depend upon movement of the waters and the nature of the sediment; those favorable to distribution are:

Favorable conditions:

(*a*) Efficient wave action prevailing from one direction oblique to the shore.
(*b*) Continuous currents.
(*c*) Uniform or gradually increasing depths of water.
(*d*) Fine or light sediment.

The reverse of these conditions favor deposition, and will be discussed in that connection.

(*a*) *Efficient, oblique wave action.*—Distribution of shore drift is fully discussed by Gilbert, and has already been referred to in stating the effect of sorting by waves of the Atlantic on

the south shore of Long Island, and the formation of barriers of wave-washed sand.

(*b*) *Continuous currents.*—Distribution by continuous currents is the condition usually assumed as having controlled the arrangement of sediments in seas of past geologic periods. In consequence of the sorting which results from different rates of settling clay is carried beyond sand, and silt is distributed more widely than clay. The prevailing current, which thus distributes, is under-tow more or less checked and assisted by tides. If the submarine slope descends from the shore steeply into oceanic depths, the force of undertow must rapidly be dissipated, but pebbles and sand move easily down the steep incline, and form a sequence of continually smaller particles, which is usually not very extended. This is the case on the western coast of South America. If, on the other hand, the seaward slope is very gentle, undertow loses force more gradually and fine sands may occur to great distances from the shore, with clay and silt deposited beyond them. This is the case off the Atlantic coast of the United States where tides probably form a powerful alternating influence; there the continental plateau is covered with sand to its outer rim, as is shown by soundings by the Coast Survey. But the force of undertow is determined in the first place by the force of waves, and it can be effective in distributing only where waves are powerful. It fails in limited seas except in a very narrow zone along shore.

Ocean currents also distribute sediments very widely. The terrigenous deposits of the Bay of Bengal and Arabian sea, mapped by Murray,[1] covering 1,600,000 square miles, owe their wide spread distribution apparently to the ocean currents which circulate east and west alternately with the changes of season in these great bays.

(*c*) *Uniform depths.*—Changes in depth of water affect the velocity of a current and thus modify its power to distribute sediment. Narrowing channel or shallowing water may cause a

[1] Scottish Geogr. Mag., Vol. V. No. 8, Aug. 1889.

current to scour and take on more load; but broadening channel or deepening water tends to cause it to deposit. The Gulf stream scours the straits of Florida and the Blake plateau, but deposits a silt bank on the lee side of the latter.[1] Only in the broad expanse of deep water does it widely distribute sediment.

(*d*) *Size of particles.*—Fine or light sediment is most widely distributed. The "blue muds" which form the terrigenous deposits beyond the littoral zone consist of particles of an average diameter of .05 mm.

Deposition occurs whenever a body of water becomes overloaded with substances in suspension or in solution. According to the condition which determines the result the deposits may be classified as mechanical, chemical and organic.

MECHANICAL DEPOSITION.

Favorable Conditions:

(*a*) Arrest and retreat of waves; beaches and sand deposits from undertow.
(*b*) Current entering still water and slowing; lake-deposits.
(*c*) Alternating currents in fresh and salt water; estuarine deposits.
(*d*) Rise of salt water surface at a river's mouth in consequence of winds, long continued from one direction; delta of the Mississippi.
(*e*) Flotation of fresh water on salt; bars of the Mississippi.
(*f*) Floculation of sediments in salt water.
(*g*) Expansion and diffusion of a current in rapidly deepening water; silt deposits on the edge of continental plateaus.
(*h*) Final subsidence from oceanic circulation.

Arrest of Waves.—(*a*) Beaches are formed where waves break. The rotary oscillation which constitutes waves in deep water becomes a motion of translation when the water shallows sufficiently and the mass of the broken wave, rushing forward,

[1] Agassiz. Three Cruises of the Blake. Bull. Mus. of Comp. Zoölogy. Harvard College. Vol. XIV.

carries up material stirred from the bottom. The finer particles are swept back by the undertow, the coarse are placed by the greater waves beyond the reach of the lesser. Thus waves, constantly in advancing, take material from the lower part of the slope to carry it up, and in retreating sweep back more or less of their load with them. If the slope be gentle they thus take from the lower to add to the upper part, and therefore they increase the declivity until the seaward profile becomes so steep that the load carried in retreat balances that advanced. This is the profile of equilibrium, which waves perpendicular to the trend of the beach do not change, unless they are of unusual force. Waves oblique to the beach-slope, scour, transport and deposit the same sands repeatedly, and if the oblique advance be prevailingly from one direction the effect is to move the beach longitudinally. Then the beach, in any one section, continues, while the supply of sand is continuous; but when the supply ceases the beach is gradually moved onward in the direction of the prevailing wave action, and the material beneath the beach sands is exposed to wave erosion.

A beach itself is but a narrow zone; it cannot constitute a wide-spread formation any more than a line can constitute a plane. But if a line be moved in one direction parallel to itself it will develop the plane, and in the same manner if a beach advances landward it may spread a formation. This advance may be a result of wave erosion, which carving a sea cliff on a bold shore planes a surface of marine denudation. The beach deposit is then a basal conglomerate. Or, the land reduced to a low surface by subaërial erosion may subside slightly in reference to sea level, and the sea, transgressing, will rearrange the superficial formations. If the waves have power to handle the material the sea is margined by beach sands. If they cannot efficiently sort it the land will merge in tide-flats with the water.

A beach is not only narrow, it is also shallow; waves build on the surface over which they break, and the height to which they may build does not exceed a few feet. Therefore, beach deposits cannot form thick strata.

The undertow rolls coarser sand and pebbles down the slope of the bottom, and carries out in suspension silt and clay with more or less fine sand. The rolling of coarser sands is promoted by a steep slope. The transportation of finer sands depends on the endurance of the undertow of a given initial strength; and this endurance will be the greater the more gradual the seaward slope and the stronger the tides. The amount of sand thus deposited is limited only by the supply, and sandy strata may, therefore, attain great thickness and have great extent seaward from a fixed beach line. If the coast be continually maintained by uplift or renewed by volcanic flows the work of the waves may be of like duration and the record will be correspondingly voluminous. Professor Chamberlin mentions the great conglomerates of Lake Superior in this connection.

Beach deposits, strictly speaking, are usually of quite coarse sand, clean and characterized by marked and irregular cross-stratification. Sand deposits from undertow graduate from clean to muddy sands, becoming ever finer seaward, and are horizontally bedded or massive.

Therefore the interpretation which may be put on strata, deposited by the arrest and retreat of waves, are:

(1) A basal conglomerate is significant of an horizon of wave erosion, due to transgression of the sea and probable subsidence of the land. If the basal contact be clean and sharp the waves probably carved a shore cliff in hard rocks. If, between the parent rock and the later sedimentary formation, there be a zone of transition composed of boulders, sand and clay of mixed mineral composition, the waves probably rearranged the cores and finer products of a surface of partial subaërial rock decay. A basal conglomerate of any variety is a definite proof of an unconformity by erosion; it is often the only fact by which such an unconformity can be distinguished from an overthrust fault.

(2) A deposit of clean sands is proof of the former existence, somewhere, of a beach on which they were washed; but the place of deposit may have been remote from the line of the beach. Coarseness of grain suggests proximity of land and vice

versa, but such suggestions need to be qualified by considering the probable fetch of the waves, the corresponding initial strength of the undertow and the declivity of the seaward slope.

A thin stratum of coarse cross stratified sands may represent a transgression by a beach-building sea over a subsiding land. A thicker stratum may have been formed by deposits from undertow behind a stationary or advancing beach line, and if such a deposit shows cross-stratification throughout, it was washed by conflicting currents, probably tidal, during its accumulation.

The deposition of beach-washed sands is consistent with constant or subsiding level of the land in relation to the sea. It does not appear that it is likely to occur during uplift from the sea except in the comparatively rare case of the rapid elevation of a bold coast range with preponderance of rock-breaking over rock-decay.

The occurrence of a stratum of sandstone is not evidence that during its formation the land furnished no other detritus. If the sands be of mixed mineralogical composition, bold declivities on land and prevalence of rock-breaking are indicated; but if the sands be chiefly quartzose it is more probable that the waves have sorted the waste of a residual mantle.

Quiet Water.—(*b*) When a current enters a body of quiet fresh water, unvexed by tides or winds, as a stream enters a lake, the inertia of the greater mass and the diffusion of the stream in the greater volume checks the current, and it drops whatever sediment it may have carried. The laws of this simple case can be formulated mathematically, and Babbage has calculated the distance to which sediments of an assumed character would be transported by a river current of assumed velocity entering a salt-water body, whose bottom has an assumed slope; he neglects the difference of density between fresh and salt water, and assumes an off-shore current equal to that of the river at its mouth.[1] The conclusion is determined in advance, and cannot be applied to the interpretation even of lake sediments, since the assumed conditions of sediment and current are hypo-

[1] Hand Book of Physical Geology, 1884. A. J. Jukes-Browne, p. 185.

thetical. An existing case, which approaches the conditions assumed by Babbage, is that of the Rio Uruguay, which is described by Revy.[1]

"The little town of Higueritas, also called Nueva Palmira, is situated in latitude 33°52'S., long. 58°23' W., in the Banda Oriental, at the junction of the Uruguay with various branches of the Parana, all of which discharge jointly their volume into the La Plata. Three miles below Higueritas, at Punta Gorda, the La Plata proper commences; three miles above Higueritas the Uruguay opens into a lake from 4 to 6 miles wide and about 56 miles long. There are no islands on this lake, although, with the exception of a deep channel half a mile wide of steep sides and submerged, the lake is shallow; it may be called the estuary of the Uruguay. A little above Fray Bentos, 58 miles from Higueritas, the first islands appear within the lake; and, their number soon increasing, we enter the delta of the Uruguay, which for 25 miles more retains the width of the lower lake, breaking, however, up into a great number of large and small islands, until, a little below Paysandu, the river proper commences within a confined channel. At Paysandu, a commercial town of importance, 125 miles from Higueritas, the delta of the Uruguay commences. At Fray Bentos the visible delta terminates; and from the latter place to the La Plata the future delta of the Uruguay is now in course of formation. . . . .

. . . . During the survey of the Uruguay there was a periodical rise of the river, viz., on February 3, 1871, and a sample of water was taken on that day at the Salto section, about 200 miles above Higueritas. The water was turbid, of deep brown color; and the analysis of the sample showed that it contained one part by weight of solid matter in suspension in 9524 parts of water. There was no perceptible change in the color of the water or in its analysis, until we reached Fray Bentos [142 miles below Salto] on the 5th February, 1871, and here it contained 1 part solid matter in 11,200 of water by weight in suspension. At Higueritas, on the same day, the waters of the Uruguay ap-

[1] Hydraulics of Great Rivers. J. J. Revy, pp. 134–135.

peared clear, and we could only trace one part of solid matter held in suspension by 25,925 of water. Nothing could more forcibly illustrate the formation of deltas. The river retains matter held in suspension by its water within its ordinary channel as long as its velocity is maintained; as soon as it enters a lake or an estuary checking regular currents, the matter held in suspension is dropped."

That is to say, in flowing 142 miles in its navigable channel and through its delta the river dropped about 15 per cent. of the load which it bore at Salto; and beyond the delta in still water it dropped 48 per cent. more; leaving it but 37 per cent. of the original load to be carried past Higueritas to the estuary of the La Plata. Or stating the proportions in terms of the sediment brought through the delta to the head of the lake, 57 per cent. was deposited and 43 per cent. escaped. It would be desirable to determine in what ratio the deposit is made in the upper and lower reaches of the lake, but Revy gives no data between Fray Bentos and Higueritas. He states however that the lake is without islands, although it is shallow with the exception of a deep channel half a mile wide; but just above Fray Bentos islands indicate the present front of the delta. The occurrence of these advance elements of the delta only in a limited distance indicates that the bulk of deposition is on the delta's front, and that the sediment which passes beyond is that which the slower current of the lake can hold in suspension.

The deposits of the extinct lakes Bonneville and Lahontan have been fully described by Gilbert and Russell, but the lake beds of the west still present rich fields for study of deposition under simple conditions in fresh and salt water.

(*c*) *Alterations of Current.*—When a land-locked water body is open to the ocean it is subject to influx and reflux of tides, but the rivers pouring into it may possess volume sufficient to exclude salt water; it is then a fresh-water estuary, which receives the sediments as well as the waters of its tributaries. The currents in such an estuary are periodic, changing with the flood and ebb, and the conditions of deposition vary accordingly. The

Atlantic coast is fringed with estuaries which are carefully mapped by the Coast Survey, but variations of deposit with changes of current have apparently not been described. Writing of the La Plata, an estuary 125 miles long, where the tide from the Atlantic contends with the current of the rivers Paraña and Uruguay, Revy says:[1]

"At this point, where the power of the tidal wave balances that of the rivers, there will be no current; the level of the estuary will rise slowly like that of a lake receiving supply from all round its border. It is here—where the rivers and the tidal wave contend for supremacy, each trying to establish its own current, and where for hours the power of either of them trembles in the balance without any sensible movement in any direction—that deposit copiously takes place; matter, held in suspension by the rivers as long as their currents are maintained agitating their water, is dropped as soon as they come to rest. It is here, within about 10 or 20 miles of the river's mouth that banks are most rapidly growing and islands are forming, and the ultimate result of these daily contests is invariably in favor of the rivers which slowly but steadily encroach on the estuary and ultimately annex its whole territory. The progress of the tidal wave is, however, never checked an instant, the rivers only check the currents originating with the wave. . . . . A tidal wave is never visible to the eye, and can only be conceived from observation, by a successive measurement of its dimensions, which are very large. We may, from an elevated position, see 10 or 15 miles, but a tidal wave on the La Plata is about 258 miles long. . . . .

". . . . During the second half of the tidal wave, viz., from flood to ebb when the surface of the La Plata is falling, there is much more uniformity in the directions of the currents, which for a time will be the same for the whole estuary, all tending to the Atlantic. The wave will again proceed faster in the deeper than in the shallower portions of the estuary, and will accordingly make the level fall a little faster in the deeper channels, and

[1] Op. cit. pp. 29–30.

the current will now set from shore into the estuary; the reverse of what happened with the rise of the La Plata.

"By degrees the level of the estuary will again adjust itself to mean sea-level. All the water which the tidal wave brought from the sea will now have to be returned, and in addition the whole volume which the great rivers have discharged into the estuary; and the currents will not only be stronger, but they will also last longer, of which circumstance the outline of the tidal wave bears evidence, the duration of the rise of the La Plata being about six hours, its fall continuing for about seven hours."

Revy further calls attention (page 23), to the fact that the current with a given fall of the river is swifter in deeper, slower in shallower water therefore deposit during flood-tide is more copious over shallows, and is there less liable to scouring during the ebb. It follows that the shallows become tide-flats, tide-flats are raised to rush-grown islands, and the islands unite to extend the river's banks. Thus the Paraña has filled two-thirds of the La Plata, which was 325 miles long, and the river will ultimately replace the estuary, so that the future delta will be built into the Atlantic, as that of the Mississippi extends into the Gulf.

If the sediment thus deposited consists of mingled sand and clay it will be sorted to some extent by the alternate checking and starting of currents. As with rising tide the current slows, sand will first be dropped; during the period of quiet water both sand and clay will sink together, though at unequal rates; and when the ebb restores the outward current, the surface of the latest deposit may be scoured, removing clay and leaving sand. Furthermore the swifter currents of the channel may carry clay, even though dropping sand, while the slower currents of the shallows drop both. Hence there must be a tendency toward alternation of more sandy layers with more clayey ones, and of horizontal passage of sands into clays.

Where rivers enter bays of such depth or expanse that the fresh water does not displace the salt water, other conditions than those governing estuarine deposition prevail. It is there

probable that the influence of tides is often subordinate to that of winds, of the difference of density between fresh and salt water, of mechanical and chemical reactions of salt water on sediments, and of currents prevailing along shore.

The influence of tides upon undertow, tending alternately to retard and accelerate the seaward current, may be important and may lead to alternate episodes of deposition and scouring as it does in estuaries; this is probably the case on all submerged continental platforms, and particularly where tides sweep in from a great expanse of ocean, as on the Atlantic coast of the United States. The effect, where conditions favor it, would be more regular than among the shoals and channels of an advancing delta, and the alternation of strata would be more distinct and even; it is possible that thinly interbedded strata of unlike character may be thus interpreted.

The well recognized characteristics of tidal formations are the evidences of shallow water, ripple marks, sun cracks, organic trails, etc., peculiar to sections of the shore where sediment is abundant. The strata are shales, and shaley sandstones irregularly bedded and often red. Such deposits are direct evidence that:

(1) The land from which they came presented gentle slopes and was mantled in residual formations to a distance from the sea.

(2) Since the zone of tide-flats along any shore is limited in width, if the distribution of such strata be wide, either great rivers gradually filled a shallow basin, as the Mississippi, the Amazon and Paraña have done, or the sea transgressed upon a low-level land. In the former case the land was built outward by volumes of muddy fresh water, and the deposits would be of fresh or brackish water types. In the latter case the sea prevailed and the deposits would be of marine character.

(3) Since the level of tidal deposits is near the surface of the water, and they are therefore limited in thickness, if a considerable thickness shows the characteristic marks throughout, the area of deposition subsided at a rate approximating to that of accumulation.

(4) Since tidal deposits are imperfectly sorted, they form under shelter from waves or in the presence of waves of force insufficient to handle the volume of sediment. The shelter may be a point of land before a bay or a barrier of beach sand before a lagoon; in either case clean sands and mud deposits may be contemporaneous. Or the feeble waves may be unequal to the task of sorting, because of short fetch in a narrow sea.

(*d*) *Long continued or powerful winds.*—The fall of a river determines its current, other things being constant, and therefore its transporting power. The fall near the mouth is lessened in any given stream if the level of discharge is raised, and vice versa, and the influence of tides in this respect has just been discussed. Winds may exercise a no less important influence. Revy (p. 27) describes an instance in which the effect upon the tides of a storm approaching from the east, combined with its subsequent direct effect in heaping up waters, was to raise the level of the La Plata fifty inches at ebb tide, and to reverse the current of the Paraña for a hundred miles. An extraordinary result like this is probably balanced in its effect upon deposition by the scouring which takes place when the wind changes direction, or calms, and the mass of water returns to its normal level. But the influence of long continued winds blowing periodically during certain seasons of the year must be effective in causing deposition from silt-laden rivers. Humphreys and Abbott briefly discuss the nature of winds affecting the level of the gulf at the mouth of the Mississippi, and assign an important share of the results from deposition to the influence of the southeast winds.[1]

(*e*) *Flotation of fresh water on salt.*—Fresh water is lighter than salt water, hence a river discharging into the ocean rises and spreads over the surface. The volume of the river, advancing, holds back the salt water, and the fresh water flows up an incline which is the surface of contact between the media of unlike densities. This checks the river's current and forms a

[1] Physics and Hydraulics of the Mississippi. Page 450.

vertical eddy or "dead angle," in which material rolled on the river's bottom is left and some sediment is dropped. Thus bars are formed in advance of deltas.[1] With rising tide or on shore winds the elevation of the salt water surface will increase this effect and force the zone of maximum deposition shoreward, while the reflux with the ebb or change of wind will lower the incline and assist wider distribution of sediment. Hence there is most rapid accumulation in the comparatively narrow strip of deposition during rising tide.

Flocculation in salt water.—Acids and salts in solution cause fine particles of sediment to draw together in flocculent form and therefore to settle more rapidly than they would in fresh water. W. H. Brewer states that clay which has been in suspension thirty months in fresh water had not settled out as clearly as the same clay from a solution of common salt in less than thirty minutes,[2] and he describes a number of experiments tending to show that "when a muddy river enters salt water chemical laws interfere with the purely mechanical ones. Then the rate of deposition is affected by the salt more than by the current, and velocities which would be more than sufficient to carry the finer suspended matter indefinitely, if the water were fresh, entirely fail where the water is brackish or salt. Practically it is the degree of saltiness which controls deposition."

Brewer applies this principle to a discussion of the formation of the bars of the Mississippi and concludes that the zone of maximum deposition retreats and advances as the greater or less volume of the river changes the position of the opposing salt water. It is obvious that this condition would be combined with that of the "dead angle" produced by the rise of the fresh water on salt.

The phenomena of flocculation have been attributed by Hilgard, Brewer and Barus to chemical reactions, but Milton Whitney finds a readier explanation in the forces of attraction or

[1] Humphreys and Abbott; op. cit. p. 445.

[2] Memoirs of the National Academy of Sciences, Vol. II, 1883, p. 168.

tension existing among the fine particles of a solid in suspension, which are modified by the presence of salts.[1] But whatever the conclusion may be as to the nature of the controlling law, the influence of salt water in this respect is an important cause of deposition of clays at the mouths of rivers.

(*g*) *Inequalities of depths; lee banks.*—When any volume of flowing water expands, it loses velocity and, if muddy, deposits sediment. This well recognized condition of river deposition has been considered in reference to a river entering a lake; it is equally true of an ocean current or of undertow, where the former passes from a narrow strait to the broader sea, or where either one flows from shallow into rapidly deepening water. The condition needs no explanation—it requires only illustration.

From the Atlantic the southern equatorial current sweeps past the mouth of the Amazon and Orinoco; as the Gulf stream it crosses before the Mississippi delta, and pouring out through the Straits of Florida enters the North Atlantic. From the rivers tributary to its course it receives fine sediment escaped beyond the deltas. In its passage through the Caribbean sea and the Gulf of Mexico it flows over the eastern Caribbean deep, Bartlett's deep and Sigsbee's deep, and where it leaves the Blake plateau north of the Bahamas it falls over the continental rim into ocean depths. Between these basins it traverses relatively shallow seas, whose bottoms are floored with modern limestone and green sand. These deeps of 2,500 to 3,000 fathoms and shoals at 100 to 500 fathoms are result of epeirogenic forces probably, but they are now floored with deposits which consist of the shells of pelagic organisms mingled with terrigenous silt, forming "modified pteropod ooze."[2] This deposition, if it has gone on long enough since the depression at the deeps, or fast enough to mask the details of deformation, possibly continued up to a recent time, determines the profiles of the slopes from shoal to abyss. In

[1] U. S. Dept. Agric. Weather Bull. No. 4, 1892, "Some physical properties of soils," pp. 19–23. Milton Whitney.

[2] Geologic and bathymetric maps of the Atlantic in "Three Cruises of the Blake," by Alex. Agassiz, Vol. I.

the Eastern Caribbean deep the declivities are such as would thus be determined; the northern and southern slopes between which the current flows are approximately equal and steep; the slope of the eastern side is also steep and lies at right angles to the course of the current in the position of a bank forming in the lee of a terrace, and the rise from the abyss westward in the direction of the current is relatively gradual.[1]

This basin is the one most advantageously situated to exhibit slopes of deposition. Bartlett's deep lies like a narrow cañon across the course of the current, and the small triangular basin immediately east of Yucatan, while it shows a steep slope northward in the direction of the current, presents similar declivities along its other two sides which are possibly scoured by the waters converging to pass out at the apex, the Yucatan channel. The steepest slope of the Gulf of Mexico from the 100th to the 2000th fathom line, is in the position of a lee-bank northwest of the Yucatan plateau, and the contours elsewhere are apparently modified by the scouring action of the current as it sweeps around the basin, and by terrigenous deposits from the adjacent shores and rivers. The Blake plateau, over which the Gulf stream sweeps north of the Bahamas, is clean, hard limestone, but a lee-bank of mud and ooze is forming on its short, steep slope into deep water. Agassiz says (p. 277): "There we pass from the comparatively coarse shore mud to finer and finer ooze, which becomes an impalpable silt in the deeper water beyond one or two thousand fathoms, assuming at the same time a lighter color."

Another illustration may be found in the deposits of silt which form the edge of the continental plateau off the North Atlantic coast of America. Agassiz has mapped the width of the plateau as covered with "silicious shore deposits," and examination of some of the samples of bottom in the Coast Survey office, for which opportunity has been most courteously extended to the writer, shows that the surface of the plateau is

[1] See bathymetric map opp. p. 98, "Three Cruises of the Blake."

composed of sands which are indeed fine near the eastern edge, yet are distinctly granular and incoherent. But soundings on the steep slope beyond the 100 fathom line have brought up very fine silt from the bank of which that slope is the surface, and this silt passes at its foot into globigerina ooze. The zone of transition from clean sand to silt is as sharp as the edge of the slope and is coincident with it. It is evident that the suspended mud which escapes beyond the estuaries and sounds of the littoral is swept out until the undertow expands over the edge of the escarpment, and is diffused in deep water; there the silt forms a great bank 10,000 feet high, with a slope of 3 to 8 degrees, which has grown seaward during geological ages, and continues to expand as erosion continues on the land.

The structure of this deposit can only be inferred, but it is worthy of consideration. The surface of accumulation, to which bedding planes are probably parallel, is inclined at a considerable angle, and traverses the bank from top to bottom obliquely to the vertical thickness. The direction of the growth is outward, not upward. The conditions of deposition are similar to those of a delta advancing into fresh water, and the structure of the deposit is probably similar to that shown by Gilbert for a fresh-water delta. (Fig. 14, p. 68, Lake Bonneville). If the detritus was sand, instead of silt, the conditions would be identical, and the bedding which would be exposed by removal of the horizontal upper layers would represent an enormous thickness of strata, inclined at a dip corresponding to the slope of the bank. Russell rejects explanations of the attitude of the Newark beds so far as they are founded on sedimentation,[1] but it seems possible that they may present the structure of lee banks. It may also be probable that isoclinal structure, where repetition of strata does not occur, is evidence of this form of deposition and of the conditions essential to it.

Deposits of this character, consisting usually of clay or silt, are significant of extended rock decay on the land, of currents

[1] Bull. U. S. G. S. No. 85, Correlation Papers.— The Newark System, p. 78. I. C. Russell.

capable of distributing the sediment, and of shoals and deeps in the sea. The amount of difference in depths is not indicated, but the rapid descent from the edge of the bank to the foot is essential to diffusion of the current and the consequent deposition. A lee-bank is a submarine terrace of construction. Where such a terrace extends into an abyss it argues prolonged development, and, therefore, antiquity of relation between continental platform and oceanic basin.

(*h*) *Subsidence from oceanic circulation.*—The greater part of terrigenous sediment must be deposited in deltas and estuaries, on continental platforms, and in silt banks along great deeps. But a very considerable amount of fine silt brought out by rivers and undertow, quantities of volcanic dust fallen on the ocean, and the calcareous and silicious parts of pelagic organisms are taken into oceanic circulation, and find a resting-place more or less remote from their place of origin. These deposits constitute the deep-sea formations; they are not clearly recognized among the strata of past geological periods now exposed in land surfaces, and on this fact rests the principal argument for the antiquity of the continents and oceans. They have been fully described by Murray,[1] and their mode of deposition need here be indicated only by reference to the blue muds of the Bay of Bengal and the Arabian Sea.

The blue muds are composed of minute mineral fragments derived from the disintegration of the land, of a diameter of .05 mm., or less, which may contain calcareous remains amounting to 50 per cent. of the whole, or may be almost free from lime. The description of a typical sample, taken about 275 miles south of the mouth of the Ganges, is given by Murray[2] in an article which is accompanied by a map showing the distribution of different formations. From this map we may gather that terrigenous deposits form a belt, 50 to 125 miles wide, along the eastern coast of Africa, the western coast of Australia, and the Malay

[1] Challenger Reports; Narr. of the Cruise, Vol. I, Part II.

[2] Scott. Geog. Mag., Vol. V, No. 8, Aug., 1889, p. 420. John Murray on "Marine Deposits in the Indian, Southern and Antarctic Oceans."

archipelago, but in the Arabian Sea and the Bay of Bengal they extend to distances of 800 miles from the mouth of the Indus and Ganges, and cover areas of more than 700,000 and 900,000 square miles, respectively. By reference to a map of the ocean currents it may be seen that their courses affect the distribution of these deposits. Sweeping at all seasons past the west coast of Australia and directly toward the east coast of Africa, parallel to which it then diverges, the principal current prevents any extended distribution of sediments in a direction normal to these coasts. But the currents of the Arabian Sea and the Bay of Bengal, flowing alternately east and west around these great embayments, past the mouths of the two great silt-bearing rivers, distribute fine material in suspension throughout the area of their circulation.

CHEMICAL DEPOSITION.

Favorable conditions:

(*a*) Evaporation from an enclosed sea.

(*b*) Precipitation of lime and magnesia from ocean waters, charged by solution from the land, through evaporation, through reaction of salt water on fresh, and through varying atmospheric conditions at the surface of the sea.

(*a*) *Evaporation of an enclosed sea.*—When a limited body of water, such as a lake, is subjected to a change of climate, so that evaporation exceeds precipitation of rain, the volume will shrink, outflow will cease, and the solution of salt will be concentrated. If the process is sufficiently continued the solution will become saturated, first for one salt, then another, and they will be deposited in the order of their insolubility. This process is important as an indication of climatic variation in the past; it has been fully described by Gilbert, Russell and Chatard for Pleistocene lakes and the chemical relations, and these studies suggest the conditions to which appeal must be made to explain the less exact facts known in ancient formations of the kind.

(*b*) *Precipitation from brackish waters.*—The chemical precipitation of lime and magnesia from sea-water is a much mooted question. There are two lines of evidence relating to it which

are apparently opposed. On the one hand, the scientists who have described material obtained by soundings on modern limestone deposits have recognized only organic remains. The Challenger in the open oceans, remote from great rivers, the Coast Survey vessels in the Caribbean, the Gulf of Mexico and off the Atlantic coast, the Norwegian expedition in the North Atlantic and English vessels in the Indian ocean have found calcareous oozes of various kinds and rocky limestone formations, but in every case the calcareous matter is described as composed wholly of the tests of pelagic organisms, many of them of microscopic size. It is known that carbonates of lime and magnesia are to a greater or less extent soluble in waters containing carbonic acid, and that the proportion of these carbonates dissolved in ocean waters is small. According to Dittmar the salts in solution in ocean waters contain 0.345 per cent of carbonate of lime and 3.600 per cent of sulphate of lime,[1] and the ocean is capable of dissolving all the lime poured into it by rivers.[2] This view being accepted, it follows that pelagic organisms, which possess the power of secreting solid carbonate of lime from solution, alone can cause lime deposits. Chemical precipitation is, according to this view, impossible, or, if it occurs, is followed by speedy re-solution, and all limestones deposited under conditions of the existing oceans are of organic origin. On the other hand, there are many limestones, deposited at different periods of geologic time, from Algonkian to the present, including some now forming, which consist of more or less clearly crystalline calcite, devoid of organic structure. If this calcite was originally built into organic forms they have been entirely obliterated. Such limestones do indeed contain fossils which sometimes exhibit more or less crystalline texture, but the occurrence of these organic forms in the holocrystalline matrix only raises the question: If the mass was originally all organic and has undergone secondary crystallization after lithifaction, why was the process so complete in the matrix

[1] Report on the Scientific Results of the Voyage of H. M. S. Challenger. "Physics and Chemistry." Vol. 1, p. 204.

[2] Op. cit. p. 221.

and relatively so ineffective in structures whose delicate anatomy can still be traced even to microscopic details? Thin sections of limestone which show a mass of interferant crystals suggest that this was the primary structure of the rock, and organic remains appear to be foreign bodies which are accidentally of the same substance as the matrix. If this view be correct, then only the alteration of the organic carbonate is the measure of the alteration of the rock-mass. If it can be shown that limestones now forming by chemical precipitation possess a crystalline structure, which resembles that of ancient limestones, the resemblance will constitute a presumption in favor of similarity of origin for the modern and ancient formations. And the fact that limestone is now being precipitated would, if it be established, leave the geologist free to weigh the evidence in the case of any ancient limestone for and against its organic or chemical origin. It is not proposed here to argue that limestones are prevailingly of one origin or the other, but only to show that the assumption of organic origin for all the calcareous deposits of the stratified series is too sweeping. To this end it is desirable to consider the chemical and mechanical conditions which affect the precipitation of carbonate of lime, to estimate the solubility of the carbonate in salt water, to review the conditions under which lime is contributed to, and distributed in, the sea, and to describe several cases of modern limestone formation by precipitation.

Schloesing made a number of experiments on the solubility of carbonate of lime in carbonic acid and water; he thus describes his method and results.[1]

"Experiments:—The method adopted was to cause to pass through pure water, which was maintained at a constant temperature and contained an excess of carbonate of lime, a mixture of air and carbonic acid, of a composition varied at will, but constant, for each experiment; this mixture was constantly supplied until a perfect equilibrium was established between the substances

[1] Comptes Rendus, Vol. 74, 1872, pp. 1552-56, and Vol. 75, p. 70.

entering into the reaction, then the quantities of carbonic acid and of lime were determined in the filtered solution.

"Then to run through the scale of pressures of the carbonic acid from the most feeble to the strongest that could be obtained.

"Then to change the temperature and re-commence anew the series of experiments in order to eliminate the influence of heat.

"The experiments establish the fact that pure water in the presence of carbonate of lime, and of an atmosphere containing a determined proportion of carbonic acid, dissolves simultaneously free carbonic acid according to the law of absorption of gases, neutral carbonate according to the solubility of this salt in water free from carbonic acid, and bicarbonate of lime."

The relation found between the tension of the carbonic acid and the proportion of bicarbonate formed is such that: "Equilibrium being established in the solution, the slightest diminution of the tension of the carbonic acid in the atmosphere determined the decomposition of a corresponding quantity of bicarbonate, with precipitation of the neutral carbonate and the emission of carbonic acid gas."

The veteran chemist Dumas, in an article on the normal carbonic acid of the atmosphere, says:[1]

"In recent times, by a happy application of the principle of dissociation, M. Schloesing has shown that the proportion of carbonic acid contained in the air was in relation with that of bicarbonate of lime held in solution in the waters of the sea. When the amount of carbonic acid (in the air) is diminished the bicarbonate of the lime in the sea is dissociated, the half of its carbonic acid passes into the air, and the neutral carbonate of lime is precipitated from solution" ("deposé").

Another condition which may decompose bicarbonate of lime is simple mechanical agitation of the water holding it in solution. Dittmar in examining samples of ocean water for car-

[1] Comptes Rendus, Vol. 94, 1882, p. 70.

bonic acid, was led to make a series of experiments on the effect of shaking with air an artificial sea-water, containing a known amount of carbonic acid. He found that he shook out 27 per cent of the carbonic acid originally present, and this did not represent the greatest possible loss. After describing the experiments he says:[1]

"The experiments reported in this chapter . . . are sufficient to prove . . . that, supposing a sea-water which contains its carbonic acid as bicarbonate, associated or not with free carbonic acid, to be exposed to the air even at ordinary temperature, such a water will soon lose not only its free but part at least of the loose carbonic acid of the bicarbonate (*i. e.*, of what is present over and above that existing in the form of normal carbonates)." Dittmar also discusses the dissociation tension of bicarbonates in sea-water and suggests that the water of the tropics constantly gives out carbonic acid to the air, and water of cooler and of arctic zones constantly absorbs it.[2]

Thus the chemists describe two conditions under which bicarbonate of lime may be decomposed into neutral carbonate and carbonic acid: 1st, by diminution of the tension of the carbonic acid in the atmosphere; 2d, by agitation of the solution.

Theoretically, either one of three things may occur to the neutral carbonate of lime if it be thrown out of solution by either one of these processes, which we may admit are active on some portions of the salt water surface. The carbonate may be redissolved, or deposited as a calcareous mud, or built into organic structures. We may discuss these alternatives in turn.

The solvent action of sea-water has been the subject of direct observation in the ocean and of experimental determination. Deep-sea shells, dredged from the bottom of the Pacific and now in the Smithsonian collection[3] are corroded, some of them on the outside only, some of them through and through. In the former

[1] Report on the Scientific Results of the Voyage of H. M. S. Challenger. "Physics and Chemistry," Prof. Wm. Dittmar, F. R. S. Vol. I, p. 115.

[2] Op. cit., pp. 212-213.

[3] For an opportunity to examine these my thanks are due to Dr. Dall, B. W.

case the creature still inhabited the shell and preserved the essential parts of its house; in the latter case the decomposition of the fleshy parts may have assisted the solution of the calcareous skeletons. To this last point Murray calls attention:[1]

"It is probable, however, that carbonic acid does play an important part in the solution of shells of animals sinking through the water. The organic matter of the animal on being oxidized produces carbonic acid, which, being itself liquid at all depths over 200 fathoms, will form a locally concentrated acid solution inside the shell, which it will attack with vigor."

The shells which were corroded while still inhabited were also exposed to unusually active solvent influences since they lay upon the bottom, of which Agassiz wi[illegible]s:[2]

"The pelagic animals derive a large part of their food supply from the swarms of large and small pelagic algæ covering the surface of the sea in all oceans. On dying, both surface animals and plants drop to the bottom, and still retain an amount of nutritive matter sufficient to serve as food for the carnivorous animals living on the bottom. A sort of broth, as it has been called by Carpenter, collects on the bottom of the ocean, and probably remains serviceable for quite a period of time; the decomposition of the organic material which has found its way to the bottom takes place gradually, and its putrefaction must be very slow." Thus these more or less corroded shells, dredged from the deep sea, bear witness to the solvent evolved in a bottom layer of decomposing organic matter.

A more direct line of evidence as to the solvent action of the sea-water itself is afforded by observations on the depths to which calcareous skeletons will sink undissolved. The pelagic pteropods and foraminifera, living at the surface, sink on dying and are slowly dissolved; if the water be too deep they never reach bottom. The limits below which they are not found are about 1500 fathoms for pteropods, thin shells exposing large

[1] Narrative of the Cruise of the Challenger, Vol. I, Second part, p. 981.

[2] Three Cruises of the Blake, Vol. I, p. 313.

surfaces to solution, and 2800 for globigerina, smaller shells, relatively more massive. Commenting on this, Dittmar says:[1]

"At the greatest depths of the oceans all these calcareous shells disappear from deposits in all latitudes. The cause of this, in my opinion, is not that deep-sea water contains any abnormal proportion of loose or free carbonic acid, but the fact that even alkaline sea-water, if given sufficient time, will take up carbonate of lime in addition to what it contains."

The solvent action indicated by the disappearance of delicate and microscopic shells, which enclose decaying organic matter, yet sink through 9000 to 16,000 feet of water, is very moderate.

Dittmar says:[2] "Sea-water is alkaline; all the alkalinity must be owing to carbonates, and of these carbonate of lime is one." Now the very moderate solvent power of this alkaline solution may be satisfied so far as carbonate of lime is concerned by two sources—by organic tests in suspension, and by chemical precipitate. The lime used by organisms is derived from the solution to which it is partly returned by re-solution, but another part is deposited, and the sea thus suffers constant loss. This loss is supplied by the land. If this terrigenous supply is less than the amount of organic deposit the sea will become less alkaline, and will more efficiently dissolve calcareous tests until the solvent is satisfied. If the land contribution is continuously equal to the amount organically subtracted, there will be equilibrium. If the land yields more carbonate of lime than that which is being locked up in organic limestones, the alkalinity of the sea will gradually increase until there is chemical precipitation. This condition is favored by the entrance of lime-bearing fresh water into a sea free from active currents and exposed to evaporation which balances the inflow.

Since the amount of lime in the ocean is thus balanced between that contributed by the land, and that precipitated by organic or chemical means, it is worth while to review the con-

[1] Op. cit., p. 221.

[2] Op. cit., p. 206.

ditions under which lime is carried from the land, and to consider how it is distributed in the sea. As was stated early in this paper, the amount of lime carried annually from a given land area is directly related to the efficiency of rock-decay; rock-decay is most efficient over surfaces which have suffered prolonged degradation, and on such surfaces the development of drainage systems has usually resulted in the growth of great rivers. Hence the lime contributed from continents to oceans is delivered chiefly at a few places, the mouths of extended systems, and there is great inequality in the distribution of these along different coasts and among different seas. Of this fact South America is the most conspicuous example, with all its great rivers pouring into the Atlantic, and not one considerable stream entering the Pacific. More limited seas, which receive vast quantities of solutions are the Caribbean and Gulf of Mexico, Arabian Sea, Bay of Bengal and Yellow Sea.

At the mouths of great rivers there exist several conditions which influence the solubility and distribution of lime in the adjacent seas; these are: 1st, the amount of lime in solution in the river water; 2d, chemical reactions between substances in fresh and salt water; 3d, the relative solubility of lime in fresh and salt water; 4th, the conditions of evaporation and agitation of the brackish water; 5th, the effects of currents.

The proportion of solids in solution in a river is dependent not only on the extent and slopes of its basin, but also on the nature of the rocks exposed, and the influence of climate on decay. Under like topographic conditions, silicious schists and a cold climate probably yield a minimum contribution; crystalline rocks and a warm, moist climate yield more; limestone areas, though resistant in a dry climate, suffer most rapid degradation under a humid atmosphere, and the deposits of the later geologic periods, including as they often do quantities of soluble salts, charge the drainage most strongly. The following analyses present specific contrasts, traceable to these geologic and climatic conditions. Each analysis represents but one phase of composition, which varies in each river with high and low

stages, and the analyses of our great rivers are incomplete, but, strange as it seems, no other analyses of their waters have been found, after diligent search.

SAMPLES.

(*a*) Ottawa river; sampled March 9, 1854, before the melting of the snow, at head of St. Anne lock; water was pale amber yellow, free from sediment and derived from a region of crystalline rocks covered with forest and marsh vegetation.[1]

(*b*) St. Lawrence river, sampled March 30, 1854, before the melting of the snow, on the south side of the Pointe des Cascades, Vaudreuil; water was clear, colorless, and represents the drainage of areas of glacial drift, crystalline rocks and paleozoic sediments, clarified by passage through great lakes.[1]

(*c*) Mississippi river;* sampled in the autumn of 1887 at very low water, in the main channel above the mouth of the Missouri; water represents drainage from areas of glacial drift, crystalline rocks and paleozoic sediments, including large expanse of limestone and cultivated lands.

(*d*) Missouri river;* sampled on the same day as the preceding; water represents drainage most highly charged with the soluble salts of the more recent and little consolidated geologic formations; potash was no doubt present but was not determined.

(*e*) Mississippi river;* six miles below the mouth of the Missouri; sampled on the same day as the preceding in the current of Mississippi water as shown by a float dropped on taking sample *c;* sample represents Mississippi and Missouri waters, apparently with excess of the latter.

(*f*) Mississippi river;* twelve miles below the mouth of the Missouri, above St. Louis; sampled on the same day as the preceding in the current indicated by the float; sample represents Mississippi and Missouri waters apparently more thoroughly mixed.

[1] Geology of Canada, 1843-63, Logan, pp. 565-568.

*Annual Report of the Water Commissioner, St. Louis, 1888, pp. 309-310. Analyses by St. Louis Sampling and Testing Works, Wm. B. Potter, Manager.

ANALYSES—PARTS PER 1,000,000 OF WATER.

Constituents.	Ottawa. *a*	St. Lawrence. *b*	Mississippi. *c*	Missouri. *d*	Missouri and Mississippi. *e*	Missouri and Mississippi. *f*
Total Solids	......	......	253.69	1207.66	1058.98	787.12
Filtered sediment	69.75	167.80	20.90	638.26	622.33	389.36
K	1.52*	1.15*	not given	not given	not given	not given
Na	2.39*	5.03*	3.37*	12.76*	9.16*	10.37*
MgO	2.36*	12.08*	28.26	41.96	37.51	39.40
CaO	13.88*	44.92*	52.93	110.15	109.63	94.90
Cl	.76	2.42	5.31	19.53	14.22	15.93
SO_3	1.61	6.87	10.28	89.76	73.66	69.89
SiO_2	20.60	37.00	not given	not given	not given	not given
	69.75	167.80	20.90	638.26	622.33	389.36
Iron and alumina	traces	traces	none	55.84	20.90	26.80

According to Gooch[1] the combination in these analyses should be calculated in the order KCl, NaCl, K_2SO_4. Na_2SO_4, $MgSO_4$, $CaSO_4$, $MgCO_3$, $CaCO_3$ Na_2CO_3, etc.; and this is the order followed in the Canadian analyses. Hence the following is the hypothetical combination.

	a	*b*	*c*	*d*	*e*	*f*
Total Solids	.....	......	253.69	1207.66	1058.98	787.12
Filtered sediment	69.75	167.80	20.90	638.26	622.33	389.36
KCl	1.60	2.20	not given	not given	not given	not given
NaCl	.....	2.25	8.57	32.03	23.30	26.38
K_2SO_4	1.22	......	not given	not given	not given	not given
Na_2SO_4	1.88	12.29	not given	not given	not given	not given
$Mg SO_4$	none	none	15.41	125.90	118.49	104.83
$Ca SO_4$	none	none	none	9.93	none	none
$Mg CO_3$	6.96	25.37	19.63	none	1.37	4.28
$Ca CO_3$	24.80	80.83	94.56	189.35	195.79	169.47
Na_2CO_3	4.10	0.61	none	none	none	none
Fe_2O_3+ Al_2O_3	traces	traces	none	55.84	20.90	26.80

The chemical reactions which take place between substances dissolved in river waters and those contained in salt water are no doubt complex; but that which is most significant in relation to possible precipitation of carbonate of lime depends upon the fact that organic matter may decompose sulphate of lime. Ac-

* Calculated from combinations given in the original publications.

[1] Analyses of Waters of the Yellowstone National Park, Bull. U. S. G. S., No. 47, p. 24.

cording to Dittmar,[1] the greater part of the lime in ocean water is there combined as sulphate, which in contact with organic matter would be reduced to sulphide with evolution of carbonic acid; the latter would attack the sulphide with formation of carbonate of lime and sulphide of hydrogen. Thus organic matter in river waters tends to increase the proportion of *carbonate* of lime in the zone of brackish water. The carbonate thus formed is added to that already existing in the river water.

The solubility of carbonate of lime in fresh water and in salt has been an object of consideration by several experimenters. Sterry Hunt testing artificial solutions found that 1 litre of water which contained 3 to 4 grams of sulphate of magnesia could dissolve 1.2 grams of carbonate of lime and 1 gram of carbonate of magnesia; but after standing a long time all the lime was deposited as hydrated carbonate.[2] Thus it would appear that the presence of the sulphate assisted the solution of the carbonates.

Experiments made by Daubrée, which contradict Hunt's results, led Thoulet to conduct a series to determine the question.[3] He took several minerals, marble, shells, coral and globigerina ooze, and subjected the comminuted samples of each separately to the action of filtered ocean water and distilled water during five weeks in each case. The solutions were shaken several times each day and the water was changed from time to time. At the close of the experiments the samples had lost in weight and the amount taken into solution, reduced to that dissolved per cubic decimeter per day, was found to be, in grammes

	In ocean water.	In fresh water.
Shells, - - - - -	.000039	.001843
Coral, - - - - -	.000201	.003014
Globigerina, - - - -	.000137	.003091

[1] Op. cit., p. 204.

[2] Dittmar, op. cit., p. 209.

[3] Oceanographié (Statique) par M. J. Thoulet, 1890, p. 263, and Comptes Rendus, t. CVIII, April, 1889, p. 753.

"One sees that the solubility in ocean water, itself very feeble, is also notably more feeble than the solubility in fresh water."

When river water enters salt water it is exposed in different form and under different physical conditions from those which existed in the river. As the fresh water is lighter than the salt, it floats upon it and spreads out in a sheet not unlike a fan. As compared with its depth and width in the river the layer is very shallow and widens from the mouth. Through waves and currents the fresh and salt water mingle, and the expanse of brackish water may be of great extent. Forchhammer attributes the minimum salinity which he found for surface water from the north Atlantic, 900 miles from the mouth of the St. Lawrence, to the volume of that river, and he found the ocean water freshened at a similar distance from the La Plata. This thin sheet of brackish water is exposed to variations of temperature and barometric pressure produced by changing winds, now on, now off shore, and is in constant agitation with the rise and fall of waves. Thus the conditions which produce varying tension of carbonic acid, and which aid the escape thereof, exist at its surface, and the bicarbonate of lime in solution must be in unstable equilibrium, with constant formation of neutral carbonate and more or less constant recombination of it. If the neutral carbonate be present in sufficient quantity it will remain in suspension, undissolved and unused by organisms, and will ultimately be deposited as calcareous ooze.

Oceanic circulation maintains an approximately uniform composition of ocean water in all parts of the open seas, and great currents sweeping past river mouths distribute the contribution of fresh water and its solid matters, whether in solution or suspension. Thus the lime brought down by rivers, though measurable by hundreds of thousands of tons per annum, is so widely diffused in the vast volume of the ocean that it escapes recognition.

There are, however, several instances of modern limestone formation which, though local, illustrate the processes of chemical deposition on a large scale. The descriptions of these may

close these suggestions concerning limestone deposition by other than organic means.

Chemically deposited limestone is forming in the southern part of Florida, probably over extensive areas. The Everglades, 4,000 to 5,000 square miles in extent, lie nearly at sea level, margined by barrier reefs which confine the surface waters; in the dry season the drainage consists of numerous small streams—in the wet season the region is all submerged save the numerous muddy islands. Explorations on the western side, from Cape Sable north to Punta Rasa, were made by Mr. Joseph Wilcox, whose observations are stated by Dall as follows:[1]

"At the north end of Lostman's Key (on the west coast, in about latitude 25° 30′) they entered the river of the same name and succeeded in penetrating 12 or 15 miles inland. No hard ground was seen except near the mouth of the river, and the highest land at the latter place was not over 3 feet above high tide. Wide, shallow bays, with muddy bottom, interspersed with low, muddy mangrove islets, comprise the scenery. The boat frequently grounded, and was obliged to wait for the rise of the tide. A small fresh-water stream was finally reached, the current of which had scoured a channel 4 to 6 feet deep, with a rough, hard, rock bottom, fragments of which were broken off. It consisted of large masses of Polyzoa more or less completely changed into crystalline limestone, the cavities filled with crystals of calcspar. The rock is very hard and compact."

"Allen's creek, emptying into Walaka inlet, an arm of Chukoliska bay, was also visited. At a point 8 or 10 miles east from the Gulf of Mexico the party were able to land on soft, wet soil, a little higher and drier than that at the head of Lostman's river. A third of a mile eastward from the head of the creek specimens were obtained of a few rocks which project above the soil. They presented molds of recent shells with the interior filled with calcspar, and an occasional *Pecten dislocatus* or *Ostrea virginica*, still retaining its shell structure. The cavities between the shells

[1] Bull. U. S. G. S. No. 84. Correlation Essays—"Neocene," by Wm. H. Dall, pp. 99–101 and 154.

were filled with hard, coarsely crystalline limestone. The rock was not coquina modified, but looked more like a fossilized oyster reef. It contained no corals, and was obviously Pleistocene. The rock formed the base of small islets of drier soil amid the marsh, on which islets grew pine trees. The marsh, apart from these islets, is probably entirely submerged in the rainy season."

In the bulletin referred to Dall speaks of the rock obtained by Willcox as being of organic or of partly organic and partly chemical origin, but at the time that manuscript was prepared the observations were less complete than now. In a recent letter he says: "Mr. Willcox's observations on the deposition of the flocculent mud from lime-bearing water were later than the original statement. The precipitated mud is more or less mechanically mixed with masses of the corrallia of Polyzoa and bivalve shells driven in shore by the sea, but these creatures do not live in the muddy water, but in the clearer water outside."

Through the courtesy of Dr. Dall the writer has examined specimens of this rock. It is a light cream-colored mass of crystalline calcite formed around the included fragments of shells. Under the microscope the unaltered structure of the organic fragments is strikingly different from that of the coarse holocrystalline matrix, in which it is apparent that the crystals developed in place. Were this a limestone of some past geologic period it would be concluded, on the evidence of the crystalline texture of some parts of it, that it had been metamorphosed and that the organic remains now visible had escaped the process which altered the matrix. But the observed conditions of its formation preclude the hypothesis of secondary crystallization. Apparently, the crystalline matrix is one primary product from solution, a rock formed in contact with the bottom, the calcareous mud is another, which, being precipitated in the solution, remains an incoherent sediment.

These results may perhaps be thus explained: The drainage of the peninsula contains an unusually large amount of lime, in consequence of the abundant supply of carbonic acid and other products of vegetable decay in the sub-tropical climate and

of the calcareous nature of all the rocks of Florida. In the Everglades this water is exposed in broad shallow sheets to active evaporation, agitation and variations of atmospheric temperature and pressure. Concentration of the solution and escape of carbonic acid, including some of that in the bicarbonate in solution, follow, and the neutral carbonate is produced in excess of the amount that can be retained in dissolved form. It is therefore precipitated in two forms—first, from the mass of the water as a flocculent mud ; second, from the lower layers of the water in contact with limestone as crystals forming an integral part of the solid rock.

The alternation of dry and wet seasons is accompanied by concentration and sluggish flow, alternating with dilution and flood currents. Therefore there are seasons of more active precipitation interchanging with those of more vigorous transportation and, perhaps, partial re-solution. In these latter seasons the calcareous mud is swept beyond the shallow basin where it forms, and enters as a suspended sediment into the Gulf circulation. What part, if any, is dissolved, what is deposited as mud in the lagoons along the coast, and what is swept into the silt banks of the Atlantic, is not known.

Conditions which produced similar results are described by Gilbert as having existed in Lake Bonneville.[1] Tufa was deposited on the shores of the lake at various stages, but most abundantly at the Provo stage, during which the water lingered longest at one level. The occurrences are thus described:

"The distribution of tufa along each shore is independent of the subjacent terrane. . . . . . No deposit is found in sheltered bays, and on the open coast those points least protected from the fury of the waves seem to have received the most generous coating. These characters indicate, first, that the material did not have a local origin at the shore, but was derived from the normal lake water ; second, that the surf afforded a determining condition of deposition."

[1] Monographs of the U. S. G. S. Vol. I, p. 167-168.

Dittmar's experiments in decomposing bicarbonate of lime by agitation indicate the nature of the condition afforded by the surf, and it appears that the neutral carbonate is capable of lithifying at the point of, and immediately upon, separation. Gilbert also says that: "Calcareous matter constitutes an important part of the fine sediment of the lake bottom, and this was chiefly or wholly precipitated from solution," and to explain the formation of the coherent and incoherent deposits of the same material from the same water he suggests that "separation was promoted by aëration of the water. All precipitation being initiated at the surface during storms, coalescence at the shore may have resulted from contact at the instant of separation."

Mr. Gilbert states (pp. 178-179), that the concentration of the waters of Lake Bonneville at the Provo stage is not definitely known. The lake had an outlet at the northern end of Cache bay, and the principal tributary, Bear river, emptied into this bay near the outlet. Cache bay was connected with the main body of the lake only by a deep but narrow strait, and it is possible that evaporation from the greater expanse of the lake exceeded the inflow of fresh water into it, while the overflow at the outlet was supplied by Bear river. In that case there would have been circulation through the strait between Cache bay and the main body, an upper current from Cache bay and an undercurrent from the lake. The straits were the scene of peculiarly copious deposition of tufa.

The tufa deposited in Lake Bonneville is of the variety described by Russell as "lithoid tufa,"[1] "of a compact and stony structure" and he concludes that it was formed when the lake waters were moderately concentrated (pp. 210-222). A limestone of similar structure is now forming on the shores of Florida, where the waves break on the beaches under conditions quite like those which determine the growth of tufa, where the surf dashed against the shores of Lake Bonneville. This rock is deposited in irregular layers, sometimes three or four feet thick, on the quart-

[1] "Geological History of Lake Lahontan," p. 190.

zose beach sands. Like the tufa, it is independent of the material upon which it gathers, but the possibility of a local supply of lime exists in the discharge of surface waters below low tide. Under the microscope the material shows a dense, fine-grained groundmass of lime with admixture of fine clay, including grains of quartz and cavities filled with coarsely crystalline calcite.

A case, which is probably more typical of what may occur now, or may have occurred in past ages at the mouths of rivers and in shallow seas, is that of the limestone deposited beyond the delta of the Rhone. This is referred to by Thoulet,[1] and is described by Lyell,[2] who says: "In the museum at Montpelier is a cannon taken up from the sea near the mouth of the river, imbedded in crystalline calcareous rock. Large masses also are continually taken up of an arenaceous rock, cemented by calcareous matter, including multitudes of broken shells of recent species." Lyell attributes the precipitation of lime to evaporation of the Rhone water, which, when it is spread upon the salt water, he compares to a lake. But this one cause is no doubt combined with the chemical and mechanical conditions which have been suggested in the preceding discussion. These conditions are favored at the mouth of the Rhone by the salinity of the Mediterranean and the absence of strong currents.

The examination of a few thin sections of limestone of different ages, from Cambrian to the present, shows that they have three principal types of structure. There are those which resemble the Everglades limestone in that they consist of more or less coarsely crystalline calcite, yet include unaltered organic remains. Of these the Trenton limestone and the marbles of corresponding age in Tennessee, which occur interstratified with unaltered calcareous shales, are the most striking examples examined. Cambrian limestones and the Knox dolomite show similar crystalline structure. The second type, the precipitated sediment which forms the muds of the Everglades and which was deposited in Lake Bonneville is represented by specimens

[1] Op. cit., p. 270.

[2] Principles of Geology, Vol. I, p. 426.

composed of exceedingly fine grained, apparently pulverulent, material; the best of these are from the Knox dolomite and the Solenhofen lithographic stone. The third variety of limestone consists of the thoroughly crystalline marbles, which contain no unaltered material, and which occur in such field relations that they are known to be completely metamorphosed. Extended study is required to determine the nature of deposition of the first and second types. They may have been organic and have suffered moderate alteration only, but there is a reasonable presumption that they did to some extent crystallize in place from sea-water, and were, to a still greater extent, precipitated from the outspread fans of fresh water, radiating from rivers' mouths, whence they spread as fine silt over the bottom of the sea.

ORGANIC DEPOSITION.

Since deposits of this character are composed chiefly of the calcareous or silicious remains of marine organisms, their formation is conditioned primarily by the circumstances controlling marine life, and secondarily by the insolubility of the skeletons under circumstances of wide distribution and gradual sinking.

Favorable conditions.—(*a*) Warm waters.

(*b*) Clear waters.
(*c*) Abundant food supply. } Conditions favorable to life.

(*d*) Depths less than 1500 fathoms.

(*e*) Expansion and diffusion of currents in rapidly deepening water.

For a description of the oceanic deposits and of the biological conditions which promote their accumulation, the reader may be referred to the Narrative of the Challenger Expedition, Vol. I, second part, pages 915 to 926. The oozes which are characterized by the predominance of remains of globigerina, pteropods, diatoms or radiolaria are there described, and it is shown that the nature of the deposit is determined by the conditions of temperature, light and motion which favor the generation of multitudes of the minute creatures whose living forms swarm at the

surface of the sea, and whose remains only enter into deposits when they have escaped being used by other creatures, or being dissolved in the ocean waters.

Agassiz, writing of the physiology of deep sea life,[1] points out that in marine, as in terrestrial, life the primary source of food for animals is in plants. The lower types of marine life, it would seem, must derive their sustenance from the water, as land plants get theirs in part from the air, and the silica and lime thus absorbed is taken directly from solution; but the creatures which live on these forms, and the carnivorous animals that feed on them, may get their lime and silica at second hand by digesting and assimilating that which the lower types take from solution. Thus the solids built from solution into organic tests may go through numberless changes before they come to rest on the bottom.

Without pursuing the discussion of biological conditions favorable or unfavorable to deposition, and without entering upon the question of coral formations, which are rarely of prominent interest in stratified deposits, the writer wishes to consider only the circumstances of limestone formation from organic remains, as that from chemical precipitates has been considered.

In discussing the solubility of shells in sea-water it has been pointed out that the layer of organic matter which accumulates at the sea bottom contains a solvent formed by the evolution of carbonic acid in the process of decay. Through this layer all substances must pass before they can become part of a lithified stratum; if they are plant tissue or flesh they will become more or less oxidized; if they are calcareous tests they will be more or less completely dissolved, and, if there be any chemically precipitated lime, arriving on the sea bottom it, too, would be dissolved in this menstruum. The earlier forms of dredge which scooped into the sea bottom, brought up a mass of ooze, formed of fine particles, burying organic forms. The later forms of dredge, arranged to skim the surface of the bottom, bring up

[1] Op. cit., pp. 312–313.

shells and organisms remarkably free from mud. Now it may be conceived that the layer of mud on which the creatures live, die, and with sunken organic remains decay, grades from the fresh surface of recent accumulations downward into a much more completely decayed and dissolved mass, and that this rests upon a surface of limestone. In the upper part of this unconsolidated stratum carbonic acid may most abundantly be evolved; in its lowest part the more concentrated solution of lime may accumulate. Then it is conceivable that lithifaction by crystallization of the carbonate of lime from the more concentrated solution is constantly proceeding on the limestone surface. If this conception be correct the formation of limestone by organic means involves the re-solution and crystallization of more or less of the calcite in the primary formation, and only those organic forms can remain unchanged which resist the solvent action. If they are delicate, as the trilobites' branchia from the Trenton limestones, described by Walcott, they give evidence that they were rapidly buried and protected.

It is thought by some that limestones are evidences of organic life at whatever period of sedimentary history they were deposited, but it has here been shown that the source of all lime in the sea is the land, and that, under conditions existing in certain localities, both crystalline limestone and calcareous mud are now forming chemically. It has also been shown that lime converted into organic forms is subtracted from that which would otherwise go to saturate the sea-water. If, then, in any early age of the earth's history, lime-using organisms were not present to subtract and deposit lime from sea-water, and if the atmospheric agencies worked then as now, the contributions from the land must have continually added to the alkalinity of the sea until chemical precipitation occurred. Such a process must have been limited to seas rather than extended to oceans, because the conditions of delivery of lime from the land were then, as now, localized. With the development of marine life and the increased demand for lime for organic use, and with the corresponding deposition of organic limestone, the sea-water must have become

less alkaline and the conditions of chemical precipitation must have been still more restricted. In time it might occur that pelagic organisms should demand so much lime for circulation from the water to calcareous algæ, to herbivorous and then to carnivorous forms, and so back into solution, that lime could escape from solution by precipitation only under exceptional conditions. If it be true that the oceanic oozes, the muds of the Caribbean, the mud-flats of Florida, and similar calcareous deposits in different seas the world over, be wholly organic, then marine life has locked up more lime than the continents could concurrently supply, and the balance is now turned against chemical precipitation. But it has not always been so.

BAILEY WILLIS.

EDITORIAL.

IN AN article on "Englacial Drift," in the July number of the American Geologist, my friend, Mr. Warren Upham, referring to my article in the first number of this Journal on the Englacial Drift of the Mississippi Basin, takes exception to the impression conveyed respecting his views in the matter of rising glacial currents. The present writer, he says, "several times speaks of the opinions of writers who believe in the considerable volume of the englacial drift, as if they supposed the glacial currents to move gradually upward from the ground to the ice surface. Such a supposition, however, seems to me quite untenable. Instead, in my own writings and those of most, if not all, of these authors, the exposure of the drift on the surface of the ice-sheet near its border, whence much of it was washed away to form the eskers, kames, and valley drift, is ascribed wholly to the superficial melting of the ice sheet, which is called ablation." I very much regret to have given expression, or to have seemed to have given expression, to the views of these writers in any other terms than they would themselves have chosen, and I cheerfully reproduce the corrective statement which Mr. Upham makes. Until my attention was called to the matter, no other interpretation of the views of these writers than that the supposed rising glacial currents moved on gradually to the surface of the ice occurred to me as possible, as no logical stopping place short of that suggested itself. I do not see any other consistent view now, but that does not affect the obligation to present accurately the views actually held. I hope these writers will credit me with attributing to them what seemed to be the most logical aspect of the hypothesis entertained by them. The supposed upward movement is attributed to differential motion

between the successive layers of ice, as stated by Mr. Upham on pages 38-9 of the article referred to (quoted below). This differential motion arises from friction at the bottom and extends to the summit. It was natural, therefore, to take it for granted that the supposed rising current extended as far as its postulated cause. It was to be assumed, of course, that the current would rise less rapidly in the upper part if the difference of movement of successive ice layers were less there than below, but it would seem that the rise must be supposed to continue *at some rate* so long as the differential motion continued, *i. e.*, until the surface was reached. The accession of snow-fall within the zone of accumulation would, to be sure, prevent erratics from reaching the new surface thus continually formed, but it would not prevent their reaching the surface in the zone of wastage. It is this latter zone with which our problems of deposition and many of our problems of derivation have chiefly to do. The career of some erratics is wholly confined to it. It goes without saying that ablation brings the surface down and is a factor in every exposure within the zone of wastage, but this does not prevent the erratics rising (by hypothesis) until they meet it. This conception of rising currents met by a plane of ablation I supposed without question to be that entertained by Mr. Upham and others. To be sure, in a strict and complete statement under this view the exposure of englacial erratics at the surface would be attributed to the joint result of the upward movement and the downward melting, but the liberties of brief and convenient statement would permit it to be referred to in terms of either factor, and I have interpreted the expressions of these writers on this basis. The correction does not, so far as I can see, in any serious way affect the main question under discussion. If there were rising currents bearing erratics to heights of 500 or 1000 feet above the base of the ice the result in ultimate deposition would be essentially the same as if the currents rose to the surface. If the rising currents are a misinterpretation, it is immaterial whether they be supposed to bear erratics to varying heights up to 500 or 1000 feet, whence these erratics move forward parallel with the base of the

ice, or whether they be supposed to continue to rise (more and more slowly) till they meet the descending plane of ablation.

If currents rise by reason of differential movements to certain heights, but not beyond them, notwithstanding the extension of the differential movements all the way up to the surface, a very distinct statement of this limitation and of the dynamics involved, qualitative and quantitative, would be appropriate. Perhaps such an explanation is intended in the following quotation from Mr. Upham, which I introduce to give ampler expression to his views, though I dissent from his interpretations of the crevasses of the alpine glaciers and of the esker, Bird's Hill, as well as from his fundamental proposition.

"The conditions of the flowing ice which seem to me to have been efficacious to carry drift upward into it from tracts of plane or only moderately undulating contour, were the more rapid onflow of the ice-sheet in its upper and central parts and even in the portion near the ground but not in contact with it, than upon the bed of the ice-sheet where its movement was much retarded by friction. A very good analogy with the slowly rising currents which I believe to have existed in many portions of the base of the ice-sheet is afforded by the edges of alpine glaciers, where the crevasses extending diagonally up stream into the glacier testify that the movement of its friction-hindered border is from the side of the valley into the ice mass. But the arched surface of the glacier and the great supply of its central current prevent the drift so worn off and borne away from being carried into the axial portion of the ice stream. Similarly the steady accession to the mass of the ice-sheet over any place by onflow from its thicker central part and by the accumulating snowfall forbade the drift of the upwardly moving basal current from being carried far into the ice in comparison with its total thickness. The evidence of the esker called Bird's Hill, near Winnipeg, Manitoba, shows that much englacial drift had there been uplifted from a nearly level country to a height of more than 500

feet in the ice-sheet.[1] Probably some of the englacial drift there was as high as 1,000 feet or more in the ice, but doubtless a larger part was below than above the altitude of 500 feet; and this was on an area where the ice-sheet had attained probably a thickness of 5,000 or 6,000 feet, its lower fifth or sixth part bearing considerable enclosed drift. In like manner the outer portions of the ice-sheet, where its thickness was less, had probably at its time of culmination no englacial drift above its lower sixth or fourth or third part. Whatever boulders and other drift became incorporated in the higher portion of the zone reached by the currents flowing upward would be thence carried forward in some regions, as from the Huronian and Laurentian areas north of Lake Huron to the boulder belts in Illinois, Indiana and Ohio, described by Chamberlin[2] without intermixture with other englacial drift brought into the ice by less powerful currents on all the intervening extent, which in the case mentioned is about five hundred miles." [3]

T. C. C.

[1] Geol. and Nat. Hist. Survey of Canada, Annual Report, new series, vol. iv., for 1888–89, pages 36–42E.

[2] "Boulder Belts distinguished from Boulder Trains—their Origin and Significance," Bulletin, G. S. A., vol. i, pp. 27–31. "The Nature of the Englacial Drift of the Mississippi Basin," Journal of Geology, vol. i, pp. 47–60.

[3] The American Geologist, vol. xii, No. 1, July, 1893, pp. 38–39.

Reviews.

Correlation Essays, Archean and Algonkian. Bulletin of the U. S. Geological Survey, No. 86. Pp. 549, 12 plates. By Charles Richard Van Hise.

In order of publication, this is the seventh of the correlation essays originally planned by the survey for the International Geological Congress of 1891. If the long delay in the appearance of the present essay is in any measure responsible for its excellence, no one will regret that it did not appear on time. This is not the first piece of good work which Professor Van Hise has done; but he has done nothing which has been of greater utility to the geological world than the present volume will prove to be.

In no department of geology has there been more rapid progress during the last decade than in the department in which Professor Van Hise is a specialist. In no department is it more difficult for those who are not specialists to follow current progress. But so successfully has Professor Van Hise written his essay that the reader will have little difficulty in knowing the present status of pre-Cambrian geology in America. He may know definitely what is definitely known, and he may know definitely what is not known. More than this, he may know definitely the limitations and imperfections of facts and principles which are but partially worked out, without finding himself confused between fact and possible fact, or between established principles and unverified hypotheses. Consciously or unconsciously, the author has given definite shape to the uncertainties and indefinitenesses of his subject, and in so doing has rendered an invaluable service to students.

A mere summary of what has been done in the various areas of pre-Cambrian rocks would be valuable. But the present essay does much more. The author is personally familiar with much of the ground brought under review in the volume, and he has given, always without a suggestion of dogmatism, what every reader is glad to have, his own opinion concerning the interpretations to be placed on the phe-

nomena of each of the regions with which he is familiar, together with the reasons therefor. The failure to summarize and interpret the summaries of the literature reviewed has lessened the value of some of the essays of this series.

The plan of the volume is simple. It consists of, first, a digest of all the papers on the pre-Cambrian geology of North America which had appeared at the time the manuscript left the author's hands; second, a discussion of the literature; and, third, a discussion of the general principles involved in the study of pre-Cambrian rocks, together with a statement of the results which have already been attained in America in the application of these principles.

The digests of the literatures are grouped on a geographical basis. The digest of all publications bearing on the pre-Cambrian geology of the original Laurentian and Huronian areas constitute one chapter, and the digests of the literature of the Lake Superior region, of the great northern area of Eastern Canada and Newfoundland, of the isolated areas in the Mississippi Valley, of the Cordilleras, and of the Eastern United States, constitute each a separate chapter. Within each area the digests are arranged chronologically. At the close of each chapter, or in some cases at the close of their subdivisions, are summaries of the results thus far attained in the respective areas. In all cases the digests appear to be as nearly absolutely impartial as it is possible for human work to be. The total number of papers summarized is between 700 and 800. Many of them are papers of considerable length, some of them being elaborate reports. When it is remembered that these papers are not roughly abstracted, but that carefully considered digests are presented, the amount of labor involved in the preparation of the bulletin will be apparent.

It is the final chapter which, together with the maps, will attract most attention. This chapter gives a concise outline history of the development of pre-Cambrian geology in America, and a clear exposition of its present status. Professor Van Hise concludes that it may be accepted as demonstrated that in North America there is an intricate system of granites and gneisses and crystalline schists, which represent the oldest rocks of the continent, and that this system underlies all known sedimentary rocks and their derivatives, and that if it ever contained sedimentary materials of any sort, all evidence of their existence has been obliterated.

It is to this system of rocks that the name Archean is restricted.

The minerals composing these rocks, wherever found, generally agree in showing evidence of extensive dynamic changes, as do also the relations of each sort of rock composing the system, to each other. So closely do the rocks of this system resemble each other in different regions, that Professor Van Hise says that a suite of specimens of Archean rocks from any one of the regions examined by him, if not labeled, "could by no possibility be asserted not to have come from any other." The system is a unit, both in its positive and negative characters.

To the Archean system thus defined are referred the basement complexes of Arizona, of the Wasatch Mountains, of certain ranges of Nevada, of Southwest Montana, of Texas, of the Lake Superior region, of the Hudson Bay region, probably the basement complex of Newfoundland, and much of the great area of Northern Canada, known as Laurentian. The basal complexes of the Front range, and of the Quartzite Mountains of Colorado, are referred to the Archean with less confidence. Still other areas not yet definitely classified may prove to be Archean in whole or in part.

With reference to the origin of the Archean, Professor Van Hise inclines to a modification of the theory that the system represents a part of the original crust of the earth. He believes that the Archean rocks were originally igneous, and that they may include not only such remnants of the pre-sedimentary crust as may exist, but those deeper parts of the crust which became lithified in later times, and which have reached the surface by denudations. He suggests that the banded and contorted granite-gneiss which serves as a background for the Archean may represent the rocks having such an origin, while the other parts of the system may be subsequent eruptives, assignable to no other system, and physically a part of the Archean.

The author does not overlook the fact that this suggestion concerning the origin of the Archean may make the system include rocks which crystallized below the outermost crust after sedimentation began, and that the date of this lithification may therefore be Algonkian, or even post-Algonkian. Their crystallization at such a date is not looked upon as sufficient reason for excluding them from the Archean group. It is manifestly impracticable to have an Algonkian system below the Archean, representing crystallization or lithification synchronous with the Algonkian sedimentation above.

This being the conception of the Archean, it is evident that strati-

graphical methods are not applicable to it. The only division which seems applicable is a bifold one, based on lithological characters and relations, viz.: 1, the more schistose rocks, generally dark colored, and 2, the more massive rocks (granites and granite-gneisses), generally light colored. To the latter class it is proposed to restrict the name Laurentian. For the former class, the coördinate name Mareniscan is proposed, the term being derived from the name of a township (Marenisco) in Michigan.

The necessity for a group between the Archean and Cambrian has come to be generally recognized during the last decade. But to all except those engaged in the study of pre-Cambrian rocks, the names which have been used to designate this group, or parts of it, have always been confusing, because of their multiplicity, their lack of definition, and the lack of uniformity in their use. This bulletin makes clear the nomenclature which has been adopted by the survey, and sets forth the relation of the various names which have been used to designate parts of the post-Archean (as here used) and pre-Cambrian group. Whether or not those not connected with the survey agree that the nomenclature officially agreed upon is the best possible, it is to be hoped that it may be uniformly adopted in the interest of intelligibility. It has the merit of simplicity and definiteness, and of avoiding disputed questions, so far as this is possible.

To the post-Archean pre-Cambrian group is given the name *Agnotozoic*, or, preferably, since its fossils are becoming known *Proterozoic*, a term coördinate with Archean, Paleozoic, etc. Since it is impossible to divide this group into systems coördinate with Cambrian, Silurian, etc., which can be correlated with each other throughout the various areas of Proterozoic rock, the term Algonkian is used for the present as a single system term to cover the whole Proterozoic group. In many areas the group is distinctly divisible into two or three systems comparable with the Cambrian, Silurian, etc. Thus in the original Huronian area there are probably two unconformable series of rocks, the lower unconformable on the Archean, and the upper unconformable below the Cambrian. These may be correlated with some degree of confidence with the Lower and Upper Huronian of the Lake Superior region. But here a third series, the Keweenawan, intervenes between the Upper Huronian and the Cambrian, and is unconformable with both. In the Grand Cañon region again, three series are recognized. But their relation to the three series of the Lake

Superior region is not known. The same is true of other regions. For this reason, the various terms, Huronian, Keweenawan, Vishnu, Chuar, etc., which have been used to designate definite parts of the group, will still be retained, for in the absence of criteria for the satisfactory correlation of the subdivisions of the group in the various regions where they occur, these parts must continue to bear local names.

The group is so extensive as to be comparable in thickness to the Paléozoic, Mesozoic and Cenozoic combined, and inferentially to represent an equal lapse of time. It contains great systems, separated by great unconformities. Concerning the two unconformities in the systems in the Lake Superior region, those between the Lower and Upper Huronian and between the latter and the Keweenawan, Professor Van Hise says: "Each represents an interval of time sufficiently long to raise the land above the sea, to fold the rocks, to carry away thousands of feet of sediments, and to depress the land again below the sea. That is, each represents an amount of time which is perhaps as long as any of the periods of depositions themselves." In parts of the region the Lower Huronian is known to be unconformable on the Archean. In other parts the relations are unknown. This statement of the case gives some idea of the thickness of the group, as well as of its complexity and importance.

The delimitation of the Algonkian is theoretically easy, after the definitions of the Archean and Cambrian. It includes all pre-Cambrian sedimentary rocks, and their igneous equivalents. Although a great unconformity generally separates the two groups, helping to render their distinction clear, it is not always easy of recognition. Locally parts of the Algonkian have undergone such profound metamorphism at the hands of dynamic forces which affected the Archean as well, that they seem to be structurally one. In such cases it is believed that the apparent conformity is in reality apparent only, the original structural relations being obscured or even obliterated by the structures superinduced by dynamic forces on both series involved. Even where there is a common structure in rocks regarded as Archean and Algonkian, there is sometimes inherent evidence that one part of the rocks concerned is clastic, while similar evidence is wanting in the other.

Not the least instructive part of the volume is the discussion of the principles applicable to Algonkian stratigraphy. It would be useless

to attempt to summarize this discussion, since it is as brief as is consistent with adequacy, in its original form. Suffice it to say that while, as applied to Paleozoic rocks, the value of lithological characters and structural relations are well understood, they have a somewhat different meaning and a greater relative value when applied to the pre-Cambrian formations. At the same time this application is more difficult.

One of the most valuable parts of the volume consists of the twelve maps, covering most of the areas where pre-Cambrian rocks are known or suspected. Nowhere else does Professor Van Hise succeed better in making the indefiniteness of our knowledge definite, than on the maps. On but two of the twelve maps does he represent Archean rocks, viz., on the maps covering the original Huronian area and its surroundings, and on the map of the Lake Superior region. Within the United States, Archean rocks are mapped in but three states — Minnesota, Wisconsin and Michigan. This does not mean that Archean rocks do not exist elsewhere, or that they are not known elsewhere, but that their areas elsewhere, so far as covered by the maps, have not been defined. Some of the areas which we have been accustomed to see represented as Archean on maps made before the Algonkian was differentiated, are now represented as "unclassified pre-Cambrian." Of this the Adirondack region may serve as an example. The maps tell us only that the rocks of this region may be Algonkian, or Archean, or both. In the text Professor Van Hise's opinion concerning the area may be found. This is to the effect that the Algonkian is certainly represented in the region, and Archean possibly, but that existing knowledge on the point is not sufficiently definite for cartographic representation. Other areas which have been mapped as Archean are represented simply as "unclassified partly or wholly crystalline rocks." Of the areas thus represented, the whole of the crystalline schist belt of the Appalachian region may serve as an example. The author's map does not even assert that these rocks, or any part of them, are pre-Cambrian. Here again we find the author's opinion in the text, where it is indicated that parts of this area are pre-Cambrian, while other extensive portions may, or may not be. Such pre-Cambrian areas as are known are not defined, and therefore cannot be represented on the maps.

Algonkian rocks find definite representation in more regions than the Archean. They appear upon the maps in Arizona, New Mexico,

Utah, South Dakota, Minnesota, Iowa, Wisconsin, and Michigan. They are known, but their areas not defined, in various other localities.

The summaries of the several chapters, or their sections, the final chapter, and the maps, should serve as a text-book on pre-Cambrian geology for all advanced students in our universities. Not only will the best information available be thus put into their hands, but the whole treatment of the subject is such as give an intelligent insight into the methods of geology, and into the methods of science as well.

ROLLIN D. SALISBURY.

ANALYTICAL ABSTRACTS OF CURRENT LITERATURE.

SUMMARY OF CURRENT PRE-CAMBRIAN NORTH AMERICAN LITERATURE.*

Cross[1] describes a series of hornblendic, micaceous and chloritic schists, on the eastern side of the Arkansas river, near Salida, Col. In places these grade into massive rocks. They are cut by granitic and pegmatitic veins, as well as by dykes of porphyry. A detailed microscopical study leads to the conclusion that the rocks are a metamorphosed volcanic series. The whole constitutes a part of a single anticline. The schists are unconformably below the Silurian, and as the known Cambrian in Colorado is a thin series of quartzites and shales conformable with the Silurian, the Salida schists are considered as pre-Cambrian. The relations of the schists to the Archean complex are not exposed, but they are probably a continuation of the hornblende-schists of Marshall Pass. Greenish schists are found at Tin Cup Pass, and near the town of Tin Cup is a highly crystalline marble inter-bedded with the green schists, and fine grained gneïssoid rocks, showing that metamorphosed sedimentary rocks do exist among the crystalline schists of the Sawatch Range. Taking into account all the facts it is thought that the schists and massive rocks of the Salida section probably represent a great series of surface lavas, erupted in Algonkian time.

Smyth (C. H.)[2] describes the rocks near Gouverneur, New York, as consisting of gneiss, granite, limestone, and sandstone, with small amounts of associated schists. The gneiss is the oldest rock of the region, underlying the other formations. It sometimes grades into a true granite, the passage being gradual. The two are regarded as different phases of the same rock, either the granite being an unchanged remnant of a Plutonic mass from which the gneiss is derived, or the result of fusion of the gneiss. Evidence of unconformity between the beds of the limestone and the foliation of the

*Continued from page 314.

[1] Series of Peculiar Schists near Salida, Col., by Whitman Cross. In Proceedings of Col. Scientific Soc., Jan., 1893, pp. 1–10.

[2] A Geological Reconnaissance in the vicinity of Gouverneur, by C. H. Smyth, Jr. In Transactions N. Y. Academy of Sciences, vol. xii., April, 1893, pp. 97–108.

gneiss was found in two localities, and was indicated in several others; there is no evidence of irruptive contacts between the gneiss and limestone; the gneiss shows no evidence of sedimentary origin; therefore, the simplest hypothesis, but requiring more proof, is that the gneiss is an eroded metamorphosed plutonic rock, upon which the limestone was deposited. The marble is coarsely crystalline, and in age is next to the gneiss. Near the base of the limestone, and interbedded with it, are peculiar schistose rocks, which, while completely crystalline and resembling igneous rocks in composition, are indicated by their field relations to be of sedimentary origin. Near Gouverneur an outcrop of limestone contains abundant fragments of black schist, scattered through the limestone in a most irregular manner, and making up, perhaps, one-third of the rock. This and other outcrops show that the schist fragments are remains of once continuous schist layers, which have been completely shattered in the course of metamorphism, since between the continuous belts of schist and the Gouverneur locality there is every possible gradation. While the schists show the effects of foldings, contortions, stretchings and shattering, the limestone shows no traces of it, it appearing to have been a plastic mass in which the schists moved with considerable freedom. The conspicuous result of metamorphism in the limestone is crystallization. In the limestones are also pegmatitic veins, which have been much shattered by the dynamic action, reducing them to small lumps of quartz and feldspar, scattered through the limestone. So far as observed the pegmatite yields to strain only by fracturing, not showing preliminary contortions, so general in the schistose layers.

In the southern part of the area examined is a granite, not grading into gneiss, and which breaks through the limestone, causing great disturbance in strike and dip, enclosing masses of the rock many feet in diameter, and metamorphosing this rock to some extent. The sandstone at Gouverneur was found in direct contact with the limestone. Here it appears that the limestone surface has been subjected to erosion before the sandstone was deposited upon it. In confirmation of this are seen narrow irregular cracks extending several feet into the limestone, which have been filled with sandstone. The limestone was evidently completely lithified when the sandstone was deposited and sifted into it, and this implies discordance. This unconformity proves that the limestone is older than the upper Cambrian, the data being wanting for any more definite determination of its age. The metamorphism of the rocks of the limestone-bearing series occurred before upper Cambrian time, but the sandstone is metamorphosed, and this metamorphism must therefore belong to post-Potsdam time.

Comments.—The inquiry rises whether the second metamorphism spoken of, that of the sandstone, is produced merely by interstitial cementation, or is dynamic metamorphism. If the first is found to be the explanation, so far as

the paper gives any evidence, all of the igneous activity and dynamic metamorphism are pre-Potsdam.

[1] Wadsworth gives a sketch of the iron, gold and copper districts of Michigan. The Azoic or Archean rocks are divided from the base upward into Cascade, Republic and Holyoke formations. These divisions are placed in order as equivalent to the fundamental complex, lower Marquette series and upper Marquette series of Van Hise. They are unconformable and represent three different geological ages. The Keweenawan is divided into two divisions, both of which are placed in the Cambrian; the Lower Keweenawan, 25,000 ft. of interbedded conglomerates and lava flows, with some intrusives; Upper Keweenawan, 12,000 feet of sandstones and shales, not separable from the Potsdam or Eastern sandstone.

The Azoic or Archean system consists of rocks formed (1) by mechanical means, (2) by eruptive agencies, (3) by chemical action.

The Cascade, or oldest formation of sedimentary and eruptive rocks, consists, commencing with the oldest, of gneissoid granites or gneiss, basic eruptives and schists, jaspilites and associated iron ores, and granites, although the above arrangement may be considered no more than a hypothesis, and it is probable that the jaspilites and iron ores will be found to belong to the Republic formation. It is also probable that the Cascade formation itself will prove to be composed of two or more distinct geological formations, as shown by the fact that the chief rock of the Huron Mountains appears to be a gneissoid granite, rather than a true sedimentary gneiss. True sedimentary gneisses are found in the Huron Bay and Cascade districts. In the former area they contain fragments that closely resemble the gneissoid granites, and thus they appear to be formed from the debris of those rocks. If, however, the gneissoid granites are metamorphosed eruptive rocks, and not true gneisses (which are restricted to metamorphosed sedimentary rocks), this fact proves only that the gneisses are younger in order of time, but not of necessity of younger geological age. Similar statements apply to the breaks between the Cascade and Republic formations, and the break between the Republic and Holyoke formations. In the Huron Bay, Menominee and other districts the Cascade formation holds intrusive granites. Amphibole-schists are also found intrusive in the gneisses in the Cascade area. In the Marquette area the amphibole schists are cut by felsite or quartz-porphyry.

Much of the granite and felsite appear to have been erupted during the time of the Cascade formation, and perhaps even later. On the Cascade range hornblende-gneiss cuts the country rock. These dykes are cut by

[1] A Sketch of the Geology of the Iron, Gold and Copper Districts of Michigan, M. E. Wadsworth, Rep. State Board Geol. Sur., Michigan, 1891-2; pp. 75-174; Lansing, 1893. Also, see Annual Reports 1888-1892, ibid., pp. 38-73.

other dykes containing crystals of feldspar, while both are cut by gray granite, that is in turn cut by red granite.

The Republic formation, commencing with the oldest division, is divided roughly as follows: Conglomerate-breccia and conglomerate-schist; quartzite; dolomite; jaspilite and iron ore; argillite and schist; granite and felsite; diabase; diorite and porodite; porphyrite. At the base of the Republic formation is a series of conglomerates and conglomerate-schists, which pass into hydrous mica-schists. Near Palmer, the coarse conglomerate rests on the gneiss to the south, and is overlaid to the north by quartzite, fragmental jaspilite and quartz-schist. The dip is about 40° northward. The conglomerate contains numerous pebbles of gneiss, as well as some of granite, diorite, schist and quartz veins. Near the Volunteer mine quartzite immediately overlies the basal conglomerate, and in other places reposes directly on the Cascade formation.

The quartzite in the Menominee district, running from Sturgeon river along Pine river to Metropolitan, is thought to belong to the base of the Republic formation, since it is found at various places close to the gneiss and granite, dipping away from them, and is cut by dykes of granite in Sec. 12, T. 41 N., R. 30 W. The dolomite occupies a low horizon, either interbedded with the quartzite or occupying its place. The fundamental ore and jaspilite appears to belong, stratigraphically, to the Republic formation. The most of the jaspilite of the formation is of detrital origin, being originally conglomerates, breccias, sands, muds, which have been subsequently chemically acted upon by percolating waters, since in the Cascade range the jaspilite and ore form layers which are frequently interlaminated with quartzite. The jaspilite of Negaunee and Ishpeming has failed to reveal any evidence that it is sedimentary, although the associated argillite and schist are in part at least clearly sedimentary. The argillite and schists are directly associated with the jaspilite and iron ore. In places they grade up into the fragmental jaspilite, and in other places are interbedded with it. They also succeed the latter rocks and overlie them. These argillites and schists are older than the diorites of the district, and are cut by them.

The Holyoke formation has the following succession, as far as known, commencing with the base: Conglomerate breccia and conglomerate schist; quartzite; dolomite; argillite; graywacke and schist; granite and felsite; diabase, diorite and porodite; peridotite, serpentine and dolomite; melaphyr or picrite; diabase and melaphyr. The conglomerate at the base of the Holyoke contains granitic material, as well as fragments from the jaspilite. In many places the unconformity between the Republic and Holyoke formations is most marked, being seen at many of the mines. In many places, also, the Holyoke formation overlaps the Republic, and is in contact with the granite and gneiss of the Cascade. Associated with the Holyoke conglom-

erate is a quartzite which includes the Mt. Mesnard and Teal Lake quartzites. In Sec. 20, T. 47 N., R. 26 W., and Secs. 8 and 19, T. 49 N., R. 28 W., near Silver Lake and in other places, sediments of the Holyoke formation have sifted down into the fissures and joints of the preëxisting rocks, when they have a dyke-like character. For such formations the term "clasolite" is proposed. The dolomite of Mt. Mesnard and thence to Goose Lake, while lithologically, like that placed in the Republic formation, is doubtfully referred to the Holyoke. Argillite, graywacke and mica-schist occur extensively in the Holyoke, constituting the upper horizon. It is doubtful whether any granite or felsite of Holyoke age exists in the Marquette district.

Diabase, diorite, porodite, and peridotite occur abundantly, belonging both to the Republic and Holyoke formations. According to Mr. Seaman, diabase dykes of the Gogebic area are probably the same as those that cut the overlying sandstones of the Keweenawan, from which it is concluded that the Keweenawan lava flows are the effusive equivalents of the Holyoke diabase dykes.

The soft hematites of the region are produced by secondary enrichment at places where the water could best act, being at points of fracturing or in basins. The silica of the lean material has been leached out, and in its place iron oxide substituted. Gold and silver veins are discussed, and a classification of ore deposits given.

The Eastern or Potsdam sandstone rests unconformably on the Azoic. This includes the unaltered horizontal sandstone, which is free from dykes of eruptive material, and the Keweenawan, which consists of lava flows alternating with sandstones and conglomerates, largely derived from the former. Above, and conformably with the Eastern sandstone, near L'Anse, is limestone of Silurian age, as shown by its fossil contents. On Keweenaw Point the Eastern sandstone dips toward, and passes under, the interstratified sandstones and lavas of the Keweenawan. At or near the contact is a fault. However, at Douglas, Houghton and Hungarian rivers, it is thought not to be at the contact, and consequently that the Eastern sandstone underlies the Keweenawan lava, but the Eastern sandstone may contain two or more sandstones of different ages, which may perhaps be considered as the most probable explanation of all the evidence. In Sec. 13, T. 46 N., R. 41 W., on the South Trap range, a nearly horizontal, soft, friable micaceous sandstone is found near the interbedded Keweenawan melaphyr and indurated sandstone. This soft sandstone contains numerous spherical spots very common in the Eastern sandstone, but not found in the Keweenawan. In the soft sandstone are found pebbles and large angular fragments of indurated sandstone, which Mr. Seaman thinks could only have been derived from the adjacent indurated sandstone. The rocks of the Trap range here exposed are believed by Mr. Seaman to hold a position near the top of the Keweenawan series, and he

concluded that the soft sandstone belongs to a distinct and later geological age than the Trap range.

The character and origin of the copper deposits are discussed.

Comments.—The major structural conclusions independently reached by the Michigan Geological Survey are nearly identical with those which have been published by the officers of the United States Geological Survey. The same may be said as to the origin of the iron ores. Upon a few points there is, however, a difference of opinion.

The unconformity which exists between the Lower Marquette and the Basement Complex marks a distinct geological age, whether gneissoid granites composing the latter are metamorphosed eruptives or metamorphosed sedimentary rocks. It is true that a sedimentary formation resting upon an eruptive, and deriving material from it, is no evidence of a geological break if the eruptive is a surface rock and has not been altered before the overlying formation was deposited. If, however, the eruptive is a deep-seated rock, or has been so sheared and folded as to take on a schistose structure before the deposition of the succeeding formation, and has consequently reached the surface by erosion, the discordance may mark as great a geological break as an unconformity between a metamorphosed sedimentary rock and an unaltered overlying series.

That there is more than one geological period represented in the Cascade formation seems unlikely, and in a later note by Dr. Wadsworth this idea is apparently abandoned. If any gneisses of the Huron Mountain prove to be unconformably upon, and to have derived material from, an older gneissoid granite series, it is probable that this new series will be found to be equivalent to the Lower Marquette or Upper Marquette series rather than to belong to the Cascade formation.

Jaspillite and ore are tentatively placed as one of the kinds belonging to the Cascade formation or Basement Complex, although the major portion of them are placed in the higher series. No large areas of this rock yet discovered would be here placed by the reviewer. The jaspillite of Ishpeming and Negaunee doubtfully referred to the Cascade is believed to be a sedimentary deposit of the same age as similar rocks of the Lower Marquette series.

That the jasper near the base of the iron-bearing formation at Cascade is interlaminated with layers of fragmental material is not sufficient evidence that the jasper is or has been derived from a mechanical sediment. The inferior formation of the lower Huronian is usually, if not always, a clastic deposit, resting as it does unconformably upon an earlier series of granites, gneisses and schists. This fragmental formation usually grades up into the non-fragmental formation of the iron-bearing member, and before continuous pure non-clastic sediments are reached there are often several alternations of the two kinds of deposits. Such occurrences are exactly analogous to the

interlaminations of limestone with shale or sandstone at the transition horizon which frequently occurs when a limestone formation rests upon a sandstone formation.

As to the age of the Keweenawan, this series is placed by Dr. Wadsworth as a lower part of the Potsdam, but is regarded by the reviewer as resting unconformably below the Potsdam, and as belonging to a different geological period. This question is one of great complexity, which can not here be discussed in detail. However, Dr. Wadsworth refers the Keweenawan so doubtfully to the Potsdam that the difference can hardly be said to be a serious one. The statement that the most probable explanation of all the phenomena at Keweenaw Point is that the Eastern sandstone is of different ages can have but one meaning—that a part of this so-called Eastern sandstone belongs to the Potsdam, and this Potsdam is later than, and unconformably upon, the Keweenaw series, which latter includes another part of the Eastern sandstone. Put in another way, Dr. Wadsworth extends the term Eastern sandstone to cover all of the sandstone exposed until the Traps are reached. That is, the break between the Potsdam and Keweenawan is in places a short distance away from the Traps. This admits the difference in geological age between the main area of Potsdam sandstone and the Keweenawan, and merely shifts the boundary line between the two a short distance. It is notable that the most important new evidence presented upon the question is that obtained by Mr. Seaman, Dr. Wadsworth's assistant. Near the South Range he finds outcrops which he regards as Eastern sandstone, holding indurated fragments derived from adjacent ledges of upper Keweenawan sandstones, and hence believes the Eastern sandstone to represent a later geological age.

It appears to the writer very doubtful whether the large number of members given for the Republic and Holyoke series will be found to be general for the Lower Huronian and Upper Huronian on the south shore of Lake Sueprior, although each may be found at some locality.

Wadsworth[1] states that recent work renders it probable that the Azoic or Archean of Northern Michigan is divisible into five unconformable formations. The tentative arrangement, commencing with the oldest, with the parallel formations, as determined by the United States Geological Survey, is as follows:

MICHIGAN GEOL. SURVEY.	U. S. GEOL. SURVEY.
Cascade Formation.	Fundamental Complex.
Republic Formation Mesnard Formation	Lower Marquette series.
Holyoke Formation Negaunee Formation	Upper Marquette series.

[1] Subdivisions of the Azoic or Archean in Northern Michigan," by M. E. Wadsworth. In Am. Jour. of Sci., vol. xlv., No. 265, Jan., 1893, pp. 72, 73.

Comments.—The suggestion of the two additional unconformities in the Huronian of the Marquette district is so tentative that no criticism of it is necessary. The suggestion implies that Dr. Wadsworth thinks this outcome the most probable one. It appears to the writer, however, that it is far more probable that the true explanation is that there are only three unconformable pre-Keweenawan series. The additional unconformities are probably suggested by the considerable local variation in the character of both the Lower Huronian and Upper Huronian series, so that in different parts of the district the same series has very different aspects.

Lane[1] holds that certain of the ore bodies of the Marquette district are produced by abstracting iron oxide from amphibolites and depositing this material at other places. The water is regarded as upward moving, hence the ore bodies rest upon the diorites as foot walls. It is not denied that in other places the iron is derived from a carbonate, or that silicia is replaced by the iron oxide. At the Volunteer mine the ore seems in part to have replaced the sandstone.

Bell reports on the Sudbury mining district:[2] The rocks are divided into three groups, in ascending order: (1) A gneiss and hornblende-granite séries — Laurentian. (2) A series comprising quartzites, massive graywackes, often holding rounded and angular fragments; slaty graywackes, with and without included fragments; drab and dark-gray argillites and clay-slates; dioritic, hornblendic, sericitic, felsitic, micaceous and other schists; and occasionally dolomites, together with large included masses or areas of pyritiferous greenstones. This group constitutes the ordinary Huronian of the district. (3) A division consisting of a thick band of dark-colored silicious volcanic breccia and black slate (generally coarse), overlaid by drab and dark-gray argillaceous and nearly black, gritty sandstones and shaly bands. The breccia is underlaid in places by quartzite conglomerate. (4) In addition to these, dikes of diabase and gabbro cut through all the foregoing, and are, therefore, newer than any of them, although they may not belong to a later geological period.

Flanking the Huronian rocks on the southeast is gneiss, and on the northwest a mixture of gneiss and hornblende-granite. The first of these rocks is of the characteristic Laurentian type, but the hornblende-granite and quartz-syenite on the northwest are not always characteristic of the Laurentian. These rocks, however, pass into the gneiss in such a way, and are mingled with

[1] Microscopic characters of Rocks and Minerals." A. C. Lane. Rep. State Board Geol. Sur., Mich., for 1891-2, Lansing, 1892, pp. 176-183.

[2] Report on the Sudbury Mining District, by Robert Bell. Annual Rep. Geol. & Nat. Hist. Sur. of Canada for 1889–90. Vol. v, Part F, p. 95, with a geological map.

them both on a large and small scale, that it was impossible to separate them. Within the Huronian trough, and parallel with it, is also a tongue of gneiss and hornblende-granite two or three miles wide and thirty-nine miles long.

The Huronian division forms a part of the great Huronian belt, extending from Lake Superior and Lake Huron nearly to Lake Mittassini. The bedding of the Huronian is usually nearly vertical, or stands at high angles. Occasionally the rocks have been sheared by pressure. Graywacke-conglomerate, in places full of rounded pebbles of gray quartz-syenite, is found on the Blue River branch of the Spanish River, Lot 2, Con. III. In the township of Hyman is an Augen-gneiss which is evidently a metamorphorsed clastic, as it forms a part of the quartzite and graywacke series. The line of junction between the Laurentian and Huronian is unusually straight. West of Lake Wahnapitae, along the contact, there is evidence of great disturbance and crushing, the rocks of the two series being much broken up and intermixed. It is not improbable that at the junction line is a considerable fault.

The third division is less altered, and is in a distinct basin running from the township of Trill northeastward to near the South Bay of Lake Wahnapitae, a distance of 36 miles, with a breadth of 8 miles in its central portion. These rocks are perhaps unconformable to the older Huronian rocks on which they rest, and may be Upper Huronian, or possibly lower Cambrian.

Along Onaping Lake and River, and along Straight Lake, are Huronian outliers. The principal kinds of rocks in the first basin are slate conglomerates, with well-rounded pebbles and boulders, mostly of binary granite, quartz, quartzite and schists; and coarse arenaceous or graywacke conglomerate, together with some pale-pink quartzites and blueish and greenish-gray felsites, argillites and slates. The principal rocks of the second basin are graywacke-schists, quartzites, quartzite or graywacke-conglomerates, green schists, hard sandstones, greenstones, and some dolomites. In the conglomerates are pebbles of graywacke and hornblende-granites like the prevailing varieties found in situ in the region, black slates and black and white quartz. On Lot 4, Con. III, Moncrieff, is the junction of the Laurentian red hornblende-granite and the graywacke.

It is concluded that the Huronian rocks of the Sudbury district are largely of volcanic nature, although many of them have been rearranged by water; hence they may be termed pyroclastic. The graywackes consist of granite debris more or less comminuted by the modifying action of water. Under this name is included many varieties of rocks, ranging from those which approach quartzites to others approaching argillites. The largest fragments are usually of red or gray aplite. As a general rule, the different divisions of the Huronian rocks do not maintain their thickness very far on the strike, but diminish more or less rapidly, their place at the same time being filled by a corresponding thickening of other members of the series.

The trappean rocks of the district consist of (1) extensive masses, together with many of smaller size, incorporated with the other Huronian rocks, and probably contemporaneous with them; and (2) dikes which cut through all the members of the series. There are nearly fifty areas of diorite, two principal belts of diabase, and a belt of slaty, greenish diorite, which in places becomes brecciated, and includes fragments, from large boulders down to small pebbles, consisting principally of quartzites, granites, and syenites.

Very numerous details are given, which cannot be summarized.

Comments.—The conclusion of Bell, that the Huronian is divisible into two divisions which are probably unconformable, corresponds with the more recent conclusions of those who have studied the Huronian of the Lake Superior region and the original Huronian of the north shore of Lake Huron. The area reported upon being a continuation of the Lake Huron Huronian, it is not surprising to find the dual character of this series continue.

No light is given upon the character of the floor upon which the earliest sedimentary rocks must have been deposited. That at several places are found water-deposited conglomerate which bear well-worn pebbles and boulders of granite, syenite, etc., which in one case are said to be exactly like the granite found in situ, seems conclusive evidence that granite and syenite existed in the region in a consolidated condition before the Huronian members containing this detritus were laid down. A part of these conglomerates clearly belong to Bell's older division of the Huronian, but this series is not divided into formations, consequently we have no information as to whether or not these conglomerates are at the bottom of the series.

Williams,[2] gives microscopical notes on various rocks from the Sudbury district. The sedimentary rocks are found to include those which are plainly clastic, those which are clastic but partially re-crystallized, and those which are highly crystalline, but probably derived from clastics. In the last division are placed felsite, gneiss-conglomerate, and gneiss. The eruptives, including various acid and basic deep-seated and surface rocks, also show extensive metamorphism and re-crystallization. Placed among the highly crystalline rock, probably derived from the clastics, are certain felsites, gneiss-conglomerates, and gneisses. Certain granites, gneisses and schists are of uncertain origin, but give no indication of clastic derivation.

C. R. VAN HISE.

[2] "Notes on the Microscopical Character of Rocks from the Sudbury Mining District, Canada," by George H. Williams. Annual Rep. Geol. & Nat. Hist. Sur. of Canada for 1889–90, vol. V, Part F, Appendix I, pp. 55–82.

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THEORIES OF THE ORIGIN OF MOUNTAIN RANGES.

MOUNTAINS are the focal points of geological interest. In their complex structure are contained all kinds of rocks, sedimentary, eruptive and metamorphic; and in their formation are engaged all geological forces in their greatest intensity. They are the culminating points, the theatres of greatest activity of all geological agencies; igneous agencies in their formation, aqueous agencies by sedimentation in their preparation, and by erosion in their subsequent sculpture. Their discussion, therefore, is a summation of all the principles of structural and dynamical geology. But they are equally important in historical geology, for the birth of mountains marks the times of great revolutions in the history of the earth, and therefore determine the primary divisions of geological time. Evidently therefore the theory of mountains lies at the very basis of theoretic geology, and a true theory must throw abundant light on many of the most difficult problems of our science.

But if this is the most important, it is also the most difficult of all geological questions. My object now is to give, as briefly as possible, the present condition of science on this subject. But in all complex subjects there is a region of comparative certainty and a region of uncertainty; a region of light and a region of twilight. My farther object, therefore, will be to separate sharply these two regions from one another, and thus to clear the ground, narrow the field of discussion and direct the course of profitable investigation.

But first of all I must define my subject. A mountain range is a single *mountain individual*—born at one time (monogenetic) *i.e.*, the result of one—though it may be a prolonged—earth-effort; as contra-distinguished on the one hand from a mountain *system* which is a family of mountain ranges born at different times (polygenetic) in the same general region; and on the other from ridges and peaks which are subordinate parts—limbs and organs—of such a mountain individual. Now a theory of mountains is essentially a theory of mountain ranges, as thus defined. In all that follows, therefore, on the subject of mountain structure and origin, we refer to mountain ranges.

STRUCTURE OF MOUNTAINS.

The origin of mountains is revealed in their structure. We must, therefore, give briefly those fundamental points of structure on which every true theory of origin must be founded.

1. *Thickness of Mountain Sediments*.—The enormous thickness of mountain strata is well known, but it is impossible to overstate its fundamental importance. We therefore give some striking examples. The Palæozoic rocks involved in the folded structure of the Appalachian, according to Hall, are about 40,000 feet thick. The Palæozoics and the Mesozoics in the Wasatch, according to King, are about 50,000 feet thick. The Cretaceous alone, in the Coast Range of California near the Bay of San Francisco, according to Whitney, are 20,000, and in Shasta county, according to Diller, are 30,000 feet thick. The Mesozoics and Tertiaries of the Alps, according to Alpine geologists, are 50,000 feet.[1] The upper Palæozoic and Mesozoic of the Uinta, according to Powell, are 30,000 feet. These are conspicuous examples, but the same is true of all mountains.

It might be objected that these numbers express the general thickness of the stratified crust everywhere—only that in mountains the strata are turned up and their thickness exposed by erosion. But this is not true. For in many cases the strata may be traced away from the mountain; and in such cases they always *thin out* as distance increases. For example, the 40,000 feet of

[1] JUDD: Volcanoes, p. 295.

Appalachian Palæozoics thin out going west until at the Mississippi river they are only 2000 to 4000 feet. The Palæozoics which in the Wasatch are 30,000 feet thin out eastward until they are only 1000 feet on the plains. It follows then that ***mountains are lines of exceptionally thick sediments.***

2. *Coarseness of Mountain Sediments.*—Mountains are composed mainly of grits, sandstones, and shales, *i.e.*, of mechanical sediments, and most conspicuously so along their axial regions. As we go from this region, sometimes in either direction, but especially in one direction, the strata become finer and finer; sandstones giving way to shales and shales to limestones, *i.e.*, mechanical to organic sediments. This is conspicuously true of the Appalachian; in so many ways a typical mountain. As we pass from the eastern ridge westward, grits and sandstones are replaced by shales and these by limestones. Therefore mountains are also *lines of exceptionally coarse sediments.*

3. *Folded Structure of Mountains.*—The folded structure of mountains is perhaps the most universal, and certainly the most significant, of all their features. But there is great variety in the degree and complexity of the foldings. Sometimes the mountain rises as *one* great fold. The Uinta is an example of this. Sometimes and oftener there are *several open* folds, like waves of the sea. The Jura is a good example of this. Sometimes and oftenest of all, there are *many closely appressed* folds. This is the case in the Coast Range of California, in the Appalachian, in the Alps, and probably in the Sierra. The Appalachian may be taken again as the type. In this range the folds are most numerous and most closely appressed in the axial region, and open out and die away in gentle waves as we go westward. Finally, sometimes in extreme cases, as in the Alps, the Pyrenees and probably the Sierra, the strata of the lateral slopes are thrust in under the central and higher parts, so that the strata of these central parts are overfolded outwards on one or both sides. This is the *Fan-structure*, so marked in the Alps and Pyrenees, where the underthrust and overfold are on both sides, but found also in the Appalachian and Sierra, where they are on one side only.

Amount of Folding.—Folded structure implies, of course, an alternation of anticlines and synclines. The number of these varies with the intensity of the folding. In the Coast Range there are apparently four or five anticlines and corresponding synclines. In the Sierra they cannot be counted, but there must be very many so closely appressed that the strata seem to be a continuous series dipping all in the same direction, *i.e.*, steeply toward the axis, for at least 30 miles. They cannot form a single series, for this would make an incredible thickness. It must be a series repeated several times by extreme folding; how many, it is impossible now to say. In the Appalachian, according to Claypole[1], there are about 19 anticlines and synclines in 65 miles and in one part—Cumberland valley—there are eight in 16 miles. In the Vaudoise Alps, according to Renevier, there are at least seven[2], and in Savoy as many as 15[3]. In many cases the foldings are so extreme that the strata first rise as folds, then are pushed over beyond the base as overfolds, and finally broken at the crest and upper limb of the fold is pushed over the lower limb many miles horizontally. In the Highlands of Scotland, according to Peach[4], by overthrust, the Archæan is brought over the Silurian and overrides it for ten miles. In the Rocky Mountains of Canada, according to McConnell[5], the Cambrian is brought over the Cretaceous and overrides it for seven miles. In the Appalachian of Georgia, according to Hayes[6], by overthrust, the Cambrian is made to override the Carboniferous for eleven miles.

4. *Cleavage Structure.*—Closely connected with the last, and having a similar significance, viz., lateral squeezing and mashing, is another structure—*cleavage*. This structure is often asso-

[1] Am'n Nat'st, Vol. 19, p. 257 and seq.

[2] Archives des Science, Vol. 59, p. 5, 1877.

[3] Archives, Vol. 28, p. 608, 1892, and 25, p. 271, 1893.

[4] Nature, Vol. 31, p. 29, 1884.

[5] Geol. Surv. Can. 1886, Rep. D. p. 33.

[6] Bull. Geol. Soc. Am. Vol. 2, p. 141.

ciated with folding and both with mountain ranges. It is not so universal as folding only because all kinds of strata are not equally affected by it; being well exhibited only in fine shales. It is important to observe that in slaty cleavage the *strike* of the cleavage planes is the same as that of the strata, and both the same as the trend of the mountain; and that the *dip* of the cleavage planes is nearly or quite vertical. Whole mountains are thus cleavable from top to bottom.

5. *Granite or Metamorphic Axis.*—Some mountains are made up wholly of folded strata. This is the case with the Appalachian, the Coast Range, and the Jura. But most great mountains consist of a granitic or metamorphic axis with stratified flanks. This is conspicuously the case with the Sierra, the Alps, and most other great mountains. So general is this, that the typical structure of ranges may be said to be—a granitic axis forming the crest, and stratified rocks, more or less folded, outcropping on the slopes. This very characteristic structure ought to be explained by a true theory of origin.

6. *Asymmetric Form.*—Mountains are not usually symmetric, with crest in the middle and slopes equal on the two sides. On the contrary they usually have a long slope on one side and a steeper, often a very abrupt, slope on the other. The crest or axis is not in the middle but nearer to one side. The earth-wave seems ready to break and often does break with a great fault on the steeper side. The Uinta is perhaps the simplest example. This range rises as a single great fold, but steeper on the north side where there is a fracture and fault of 20,000 feet vertical. Of course in this as in all cases the original fault-cliff has crumbled down to a steep slope, or even been destroyed entirely. The Sierra and Wasatch are remarkable examples of asymmetry. The Sierra rises on the west side from the San Joaquin plains near sea level by a gentle slope fifty to sixty miles long, reaches its crest near 15,000 feet high and then plunges down by a slope so steep, that the desert plains on the east, 4,000 to 5,000 feet above sea level is reached in six to ten miles. There is on this side a fault-cliff nearly 11,000 feet high. The Wasatch

has a similar form, except that the fault-cliff looks westward instead of eastward. It is true that the extreme asymmetry of these two mountains was given them long after their origin and by a different process to be presently described. But even before this last movement they were probably asymmetric, though in a less degree. The Appalachian is perhaps here again a typical mountain. Its long slope is to the west and its crest close to the eastern limit. The Alps, the Appenines, the Carpathians, and the Caucasus, according to Suess, are foreign examples of the same form.

There are many other interesting points of structure that might be mentioned, but they are less significant of mode of origin and therefore omitted in this rapid sketch.

ANOTHER TYPE OF MOUNTAINS.

I have given the main characteristics of mountains of the usual type, of which the Appalachian, the Coast Range, the Alps and Pyrenees may be taken as good examples. But there is another type, different in structure and in mode of origin, to which attention, I believe, was first called by Gilbert. It is doubtful if they are found anywhere except in the Basin and Plateau regions, and therefore the type may be called the Basin region type. The Basin and Plateau regions are broken by north and south fissures into great crust-blocks which by gravitative readjustment have been tilted, *i. e.*, one side heaved up and the other side dropped down, so as to form a series of north and south ridges and valleys. Each ridge rises by a long slope on one side to a crest and then drops by a steep fault-cliff on the other. The ridges therefore are extremely asymmetric but the asymmetry is produced in a different way from that of the usual type. In a word, these mountains seem to be the result of a series of enormous parallel faults. Such faults are common everywhere, but do not usually give rise to any inequalities which may be dignified by the term mountain: or if so at one time, have since been levelled by erosion. But those in the Basin region are on so grand a scale and so recent in time, that they form

very conspicuous orographic features. I have sometimes doubted whether they should be called ranges at all; but when we reflect that at least 10,000 feet of the height of the Sierra is due to normal faulting, it seems impossible to withhold the term. Thus mountains may be divided into two types, viz., mountains formed by folding of strata and mountains formed by tilting of crust-blocks. The structure of the one is *anti*clinal or *di*clinal, of the other *mono*clinal. The Sierra probably belongs to both types. It was formed at the end of the Jurassic as a mountain of the first type, but the whole Sierra block was tilted up on its eastern side without folding, at the end of the Tertiary, and it then became also a mountain of the second type.

A complete theory must explain this type also; but since from its exceptional character it must be regarded as of subordinate importance, we shall be compelled to confine our discussion to mountains of the usual type.

EXPLANATION OF THE PRECEDING PHENOMENA.

In all cases of complex phenomena there have been many theories, becoming successively more and more comprehensive. The citadel of truth is not usually taken at once by storm, but only by very gradual approaches. First comes the collection of carefully observed facts. But bare facts are not science. They are only the raw material of science. Next comes the grouping of these facts by laws more or less general. This is the beginning of true science. Every such grouping or reducing to law is a scientific explanation, and therefore in some sense a theory. At first the grouping includes only a few facts. The explanation or theory lies so close to the facts as to be scarcely distinguishable from them. It is a mere corollary or necessary inference. It is modest, narrow, but also in the same proportion *certain*. Then the group of explained facts becomes wider and wider, the laws more and more general, and the theory more daring (but in the same proportion also perhaps more doubtful): until it may at last include the Cosmos itself in its boundless but shadowy embrace.

Now in this gradual approach toward perfect knowledge, there

are two very distinct stages. The one consists of explanation of the immediate phenomena in hand. This gives the laws of the phenomena, and may be called the *Formal Theory*. The other explains the cause of these laws, and may be called the *Causal or Physical Theory*. All science passes through these two stages. For example: Until Kepler, the phenomena of Planetary motion were a mere chaotic mass of observed facts without uniting law. Kepler reduced this chaos to order by the discovery of the three great laws which go by his name. This is the *formal* theory of Planetary motion. But still there remained the question, why do planets move according to these beautiful laws? Newton explained this by the law of gravitation. This is the causal or *physical* theory.

But this is so important a distinction that I must illustrate by examples taken from geological science. All the phenomena of slaty cleavage are completely explained by supposing the whole rocky mass to have been mashed together horizontally and extended vertically. This is the Formal theory and may be regarded as certain. But still the question remains: How does mashing produce easy splitting in certain directions? The solution of this question is the Physical theory, and is perhaps a little more doubtful, though I think satisfactorily answered by Tyndall. But still there remains a deeper and more doubtful question, Whence is derived the mashing force? Is it general interior contraction, as some think, or is it local expansion as others think. A perfect theory must answer all these questions. Take another example: All the phenomena of the drift are well explained by the former existence of an ice sheet moving southward by laws of glacial motion, scoring, polishing, and depositing in its course. This is the Formal theory. But still the question remains, What was the cause of the ice sheet? Was it due to northern elevation, or to Aphelian winter concurring with great eccentricity of the earth's orbit? And if due to northern elevation, what was the cause of that elevation? A perfect theory must answer all these questions. Take one more example: All the phenomena of earthquakes are completely explained by the emergence on the surface

and a spreading there from a centre, of a series of elastic earth-waves. This is the Formal theory. It explains the immediate facts observed here on the surface, but no more. But still remains the question, What is the *cause*, deep down below, of the concussion which determined the series of earth-waves. This, the physical theory, is far more doubtful. Or the theory may be made still deeper and proportionately more doubtful. If our theory of the cause of the interior concussion be the formation of a fissure or readjustment of a fault, as seems in many cases probable, there would still remain the question of the cause of great fissures and of their subsequent readjustment by slipping. This is probably as far as geological theory would go: for although cosmogony may go still farther, the interior heat of the earth is usually the final term of strictly geological theories.

I have made this long detour because I wish to keep clear in the mind these two stages of theorizing in the case of Mountain Origin. The formal theory is already well advanced toward a satisfactory condition; the physical theory is still in a very chaotic state. But these two kinds of theories have been often confounded with one another in the popular and even in the scientific mind and the chaotic state of the latter has been carried over and credited to the former also; so that many seem to think that the whole subject of mountain-origin is yet wholly in air and without any solid ~~the~~ foundation.

I. FORMAL THEORY.

A true formal theory, keeping close to the immediate facts in hand, must pass gradually from necessary inferences from smaller groups, to a wider theory which shall explain them all.

Inferences from 1 and 2, i. e., Thickness and Coarseness of Sediments.—The thickness of mountain sediments, as we have seen, is greatest along the axis and grows less as we pass away from that line. Now where do we find lines of very thick sediments forming at the present time? The answer is: On sea bottoms closely bordering continents. The whole washings of continents accumulate very abundantly along shore lines and thin out sea-

ward. Mountains were therefore born of sea-margin deposits. This view is entirely confirmed by the character of mountain sediments. We have seen that these are coarsest near the crest, becoming finer and then changing into limestones as we pass farther and farther away from the crest. Now this is exactly what we find in off-shore deposits. They are coarse sands and shingle near shore, and then become progressively finer seaward, until in open sea beyond the reach of even the finest mechanical sediments, they are replaced by organic sediments which form limestones. It seems evident, therefore, that the place of a mountain-range before mountain-birth was a marginal sea-bottom receiving abundant sediment from a contiguous continental land-mass. This explains at once the usual position of mountains on the borders of continents. Here, then, is one important point gained.

But such enormous thickness as we often find would be impossible unless the conditions of sedimentation on the same spot were continually renewed by *pari passu* subsidence of the sea-bottom. And we do indeed find abundant evidence of such *pari passu* subsidence, not only at the present time in places where abundant sediments are depositing, but also in the strata of all mountain ranges. In the 40,000 feet thickness of Appalachian strata nearly every stratum gives evidence by its fossils, of shallow water, and often by shore marks of all kinds, of *very* shallow water. Therefore the place of mountains while in preparation, in embryo, before birth, *was gradually subsiding, as if borne down by the weight of the accumulating sediments*, and continued thus to subside until the moment of birth, when of course a contrary movement commenced. The earth's crust on which the sediments accumulated was bent into a great trough, or what Dana calls a Geo-Syncline. This is another important poined gained.

But let us follow out our logic. If the earth's crust yields under increasing weight of accumulating sediments, then ought it also to rise under the decreasing weight of eroded land surfaces. If it sinks by loading it ought also to rise by unloading.

And such indeed seems to have been the fact. For if all the strata which have been removed from existing plateaus and mountains were restored, it would make an incredible height of land. At least 10,000 to 12,000 feet have been carried away by erosion from the Colorado Plateau region and yet 8,000 feet remain. At least 30,000 feet have been worn away from the Uinta Mountains and yet 10,000 feet remain. Evidently there has been a rise *pari passu* with the lightening by erosion.

May we not then safely generalize? May we not conclude with Dutton that the earth in its general form and in its greater inequalities is in a state of gravitative equilibrium—that the earth is oblate spheroid, only because this is the form of gravitative equilibrium of a rotating body; that ocean basins and continental protuberances exist, only because the materials underlying the former are denser, and underlying the latter lighter than the average. It is true that the spheroid form of the earth and the sinking and rising of the crust by loading and unloading may be explained on the supposition that the earth is liquid beneath a thin crust, but to this view there are three fatal objections. 1. The cosmic behavior of the earth is that of a rigid solid. This I believe to have been demonstrated. 2. The existence of the present great inequalities of the earth would be impossible, except under the most improbable conditions. For example, if the earth be fluid then the crust must rest as a floating body. But if so, then, by the laws of floatation, for every continental protuberance on the upper side there must be a corresponding protuberance in reverse on the other side of the crust, and for every great plateau or mountain range there must be a corresponding plateau or mountain range in reverse. And taking the difference of specific gravity of the floating crust and the supporting liquid to be as great as that between ice and water, these reverse inequalities must be ten times as great as those at surface! Can we accept so violent an hypothesis? But (3) repeated experiments, especially very recent ones by Carl Barus,[1] prove that rocks

[1] Am. Journal, vol. 45, p. 1., 1893.

increase very notably in density in the act of solidification, so that a solid crust would undoubtedly break up and sink in a liquid of the same material. But how then are we to explain gravitative equilibrium in the case of a rigidly solid globe. I answer, by two suppositions. 1. That the earth, though rigid as glass or even steel, to *rapidly* acting force, yet yields *viscously* to heavy pressure *over large areas* and acting *for a long time*. A solid globe of glass six feet in diameter will very perceptibly change form under its own weight. How much more the earth under its own gravity. This completely explains the oblateness of the earth even if solid throughout and had never been liquid at all. The earth, though rigid, behaves like a very stiffly viscous body; like, for example, the ice of glaciers though very much more stiffly viscous. This viscosity would not at all interfere with its rigidity under the tide-generating influences of the sun and moon — for these are far too rapidly acting.

2. The second supposition necessary is, that the earth is *not* absolutely *homogeneous* either in density, or in conductivity for heat, that in secular cooling and contraction the denser and more conductive areas, cooling and contracting faster, went down and became the ocean basins, while the lighter and less conductive areas were left as the more prominent land surfaces. And thus to-day the ocean basins are in gravitative equilibrium with the continental areas, because in proportion as oceanic radii are shorter are the materials also *denser;* and in proportion as the continental radii are *longer*, are the materials also specifically *lighter*. This condition of gravitative equilibrium Dutton calls *Isostasy*.

Thus then the great inequalities of the earth, constituting ocean basins and continental surfaces, are the result of *unequal radial descent of the earth's surface* by contraction in its secular cooling. This is by far the most satisfactory theory of these *greatest* inequalities.

In thus following the phenomena of Isostasy to their logical conclusion, we seem to have gone beyond the limits of our subject, which is the *theory of mountains:* but the close connection which probably exists between the cause of continents and the

cause of mountains justifies the digression, if such it may be called.

Inferences from 3 and 4, Folding and Cleavage.—Still adhering closely to observed facts, there are some necessary inferences from folded structure and cleavage. These structures are indisputable proofs that mountain strata have been subjected to enormous *lateral* pressure at right angles to the trend of the axis, by which the whole mass has been mashed together horizontally. But such horizontal mashing must of necessity produce corresponding up-swelling along the line of yielding. In a word, it is evident that mountains have been uplifted largely, at least, if not wholly, by horizontal mashing. The only question that remains is, Is lateral mashing alone sufficient to produce the highest mountains? Let us see.

The amount of uplift in such cases would depend on two things, viz., the thickness of the strata and the amount of mashing. Now, as already shown, mountain sediments are 30,000, 40,000 and even 50,000 feet thick. The amount of mashing in many mountains is almost incredible. In the Appalachian it is so extreme that in one place, according to Claypole, ninety-six miles of the original sediments have been crowded into sixteen miles, and the shortening of the whole Appalachian breadth is estimated as eighty-eight miles.[1] In the Alps the shortening is estimated by Heim at seventy-two miles or one-half the original breadth of the sediments.[2] In a word, we may without exaggeration say that, in great mountains, the original space is to the folded space as two to one, or even three to one. Now a crushing of 30,000 feet of sediments into one-half their original space would double their thickness, which is equivalent to a clear elevation of 30,000 feet. But strata are 40,000 and even 50,000 feet thick. Evidently then this method alone is sufficient to account for the highest mountains in the world, even allowing for the enormous erosion which they have suffered.

The same is equally shown by the phenomena of slaty cleav-

[1] Amn. Natst. Vol. 19, p. 257.

[2] HEIM: Archives des Sciences, Vol. 64, p. 120, 1878.

age so often associated with folded structure. Slaty cleavage, as has been demonstrated by experiment, as well as by field observation, is produced by a mashing together of the whole rocky mass in a direction at right angles to the cleavage plane and a corresponding extension in the direction of the *dip* of these planes. Now since the cleavage dip is usually nearly or quite vertical, this means a mashing together *horizontally* and a proportionate extension *vertically*. The amount of mashing together horizontally and extension vertically has been in many cases somewhat accurately estimated. In this case also, as in folding, we have evidence of a mashing of two or even three into one and a corresponding extension vertically of one into two or even three. This amount of extension affecting thick strata is sufficient to account for the highest mountains in the world without resorting to any hypothetical force pushing upward from beneath.

There seems therefore to be no reasonable doubt that *mountains are formed wholly by lateral crushing with proportionate upswelling*. This is a very important point gained. Let us hold it fast. This brings me naturally to the next point.

Inferences from 5 and 6, Granitic Axis and Asymmetric Form.—A granitic or metamorphic axis is a very general, though not a universal, characteristic of mountains. The old idea (still held by some) was that fused matter was pushed up through and appeared above, the parted strata along the crest as the granite axis, lifting the strata, as it were, on its shoulders to form the slopes. But it must be observed that the axis is often only metamorphic, not granitic, and moreover that some mountains are composed wholly of folded strata alone. If, therefore, we regard granite as often only the last term of metamorphism, we may more properly speak of the axis of mountains as metamorphic. If so, then it is not necessary to suppose any vertical uprising of fused matter by volcanic forces at all. On the contrary, we would explain the axis thus :

It is evident that accumulating sediments must cause corresponding rise of the interior heat of earth toward the surface so as to invade the lower parts of the sediments and their included

water. Now it is well known from the experiments of Daubreé and others, that in the presence of water, even in small quantities, rocks become softened and even hydrothermally fused at the very moderate temperature of 400° to 800° F. It is certain then that such thickness of sediments as we know accumulated in preparation for mountain birth, must have been softened to a degree proportionate to the thickness, and therefore perhaps semi-fused or even fused in their lower parts along the line of *thickest* deposit, and therefore of greatest subsequent elevation. On cooling after elevation, this sub-mountain fused or semifused matter would form a granitic or metamorphic *core* beneath the highest part. The appearance of this core as an axis along the crest is the result not of up-thrust but of *subsequent erosion* greatest along this line.

And this, in its turn, furnishes a key to the location of mountains along lines of thick sediments. For not only the lower parts of such sediments but also the sea-floor on which they are laid down would be hydrothermally softened or even fused. Thus would be determined a line of *weakness*, and therefore a line of yielding to lateral thrust, and therefore also a line of crushing, folding, and upheaval. The folding and the upswelling and the metamorphism would be greatest along the line of thickest sediments and become less as we pass away from that line. In extreme cases, however, the firmer lateral portions might be jammed in under the softer central portions, on one or both sides, and give rise to the Fan-structure character of complexly folded mountains. Or again, in such cases the folds might be pushed clean over and broken at the bend, and then the upper limb slidden over the lower limb even for miles, forming the wonderful thrust-planes of the Alps, the Appalachian and the Rocky Mountains, already described. Thus the phenomena under (5) is completely explained.

But mountains are usually asymmetric, the crest being on one side. This is explained as follows: Sedimentary accumulations along shore lines are thickest *near* shore (though not *at* shore) and thin out slowly seaward. The cilinder-lens formed by sedimentation is not symmetric, its thickest part being near one side, and

that the shore side. This thickest line, as we have seen, becomes the crest, which therefore is asymmetrically placed on the land-side or side from which the sediments were derived. The over-folding on the contrary is to the sea-ward.

SUMMARY STATEMENT OF THE FORMAL THEORY.

We may therefore group all these inferences and sum up our view of the mode of mountain formation thus:

1. Mountain ranges, while in preparation for future birth, were marginal sea-bottoms receiving abundant sediment from an adjacent land-mass and slowly subsiding under the increasing weight. 2. They were at first formed, and continued for a time to grow, by *lateral pressure* crushing and folding the strata together horizontally and swelling them up vertically along a certain line of easiest yielding. 3. That this line of easiest yielding is determined by the hydrothermal softening of the earth's crust along the line of thickest sedimentation. 4. That this line, by softening, becomes also the line of greatest metamorphism; and by yielding, the line of greatest folding and greatest elevation. But (5) when the softening is very great sometimes the harder lateral strata are jammed in under the crest, giving rise to Fan-structure, in which case the most complex foldings may be near but not at the crest. Finally (6) the mountains thus formed will be asymmetric because the sedimentary cilinder-lenses from which they originated were asymmetric.

SOME EXAMPLES ILLUSTRATING.

It is hardly necessary to enforce these views by illustrative examples. They at once arise in the mind of every geologist. But there are those in this audience who are not geologists. I therefore select a few examples among our own mountains.

1. *Appalachian.* It is well known that during the whole Palæozoic, the region now occupied by the Appalachian was the eastern marginal bottom of the great interior Palæozoic Sea, receiving abundant sediments from an eastern land mass of Archæan rocks, which then extended far beyond the present limits of the continent and whose western coast-line was a little to the east

of the present Appalachian crest. The sediments along this marginal sea-bottom increased in thickness during Cambrian, Silurian, Devonian and Carboniferous (with some changes of Physical Geography, but without greatly changing the line of sedimentation) until 40,000 feet thickness was reached. Such thickness, of course, could not be attained without *pari passu* subsidence. We have additional evidence of this in shallow water fossils and even shore marks at many levels in the series. At the end of the coal period, when 40,000 feet had accumulated, the increasing softening along the line caused it finally to yield to horizontal thrust; the whole mass of strata was crumpled together and swelled up along the line of sedimentation and the Appalachian Range was born. The same forces which caused its birth continued to cause its *growth* for a long time. Subsequent erosion has sculptured it into its present form, but *has not exposed its granite core*. The crest is on the east or landward side, as we should expect, and the overfolds are to the west or toward the sea of that time. This is perhaps the most typical example we have.

2. *Sierra.*—If it were not for a subsequent movement so late as the beginning of the Quaternary, which greatly modified its form, the Sierra too would be a typical range. During the whole Palæozoic and the greater part of the Mesozoic the place now occupied by the Sierra was the eastern marginal bottom of the Pacific, receiving sediments from a continental land-mass in the present Basin region. The shore line changed somewhat at the end of the Palæozoic, but the Sierra region maintained a sea bottom position. At the end of the Jura, when an enormous thickness had accumulated, the increasing softening of the crust determined a yielding to lateral thrust and consequent formation of the range. Subsequent erosion has completely removed the strata from the crest and exposed the granitic core as an axis[1]. This axis is here also on the landward side, and the overfolds are

[1] Sierra granite is not Archæan as has been asserted by some, nor does it all antedate the birth of the range. This is proved (1) by the gradation traceable between slates and granites, and (2) by the fact stated by Whitney, by Fairbanks, and by Diller—that the granite in many places penetrates the slate as veins.

to the seaward as in the Appalachian. The erosion of the Cretaceous and Tertiary times probably cut down the Sierra to very moderate proportions and reduced it to an almost senile condition. At the end of the Tertiary a great fault and bodily uplift of the whole Sierra block on its east side transferred its crest to the extreme eastern margin, greatly increasing its height and rejuvenating its erosive vigor.

3. *Coast Range.*—The formation of the Sierra transferred the coast line westward of that range and the present place of Coast Range became marginal sea-bottom, receiving sediment from a now greatly increased land-mass. This continued until the end of the Miocene when the Coast Range was similarly formed.

We might multiply examples, but these are deemed sufficient to illustrate the principles.

MINOR PHENOMENA.

We have given only the most fundamental phenomena, *i.e.*, those which reveal the mode of origin, and upon which, therefore, a true theory must be founded. But all other minor phenomena associated with mountains are well explained by the view above presented and their explanation confirms the view. For example:

1. *Eruptive Phenomena.*—We have seen that beneath a mountain, before and at the time of its formation, there is a deep-seated core of liquid or semiliquid matter. Also it is evident that the strong foldings of the strata in the act of mountain formation must produce fissures parallel to the folds and to the mountain axis, and that these fissures may reach down to the submountain liquid matter. In the act of mountain formation, therefore, the submountain liquid must be squeezed into the fissures forming dikes, or through the fissures and poured out on the surface as great lava floods, covering sometimes thousands of square miles. In most cases subsequent erosion has swept these overflows clean away leaving only their roots as intersecting dikes. Only the most recent still remain. On these great fissure-eruption lava-fields, ordinary volcanic or crater eruptions continue for ages

after the mountain formation ceases. In these, however, materials are ejected not by mountain-making forces, but by the elastic force of vapor from percolating waters. All these eruptive phenomena are, therefore, associated with mountain ranges.

2. *Faults.*—In folding, and especially overfolding, the strata are, of course, often broken and the upper wall of the fissure is pushed over the lower wall by horizontal thrust often thousands of feet, forming reverse faults and so-called thrust planes. Hence this style of faults are everywhere associated with strongly folded rocks, and, therefore, with mountains, and are indisputable evidence of horizontal crushing. In other places than mountains, and in horizontal or gently folded rocks, the other style of faults, *i. e.*, normal faults, are more common.

3. *Mineral Veins.*—The filling of fissures at the moment of formation with fused matter constitute dikes; but if not so filled, they are afterwards filled by a slow process of deposit from circulating waters and then they form mineral veins. These, therefore, are also common in mountains.

4. *Earthquakes.*—Again, the immense dislocations of strata which we find in faults did not occur all at once, but slowly through great lapse of time; and yet on the other hand not by uniform slipping, but by jerks, a little at a time. Every such readjustment of the walls of a fissure, whether by increasing lateral pressure (reverse faults) or by gravity (normal faults), gives rise to an earthquake. Earthquakes, therefore, although not confined to, are most common in mountain regions, especially if the mountains are still growing.

Thus, leaving out the monoclinal type which seems to belong to different category, all the phenomena, major and minor, of structure and of occurrences connected with mountains, are well explained by the theory of *lateral pressure* acting on lines of thick sediments accumulated on marginal sea-bottoms and softened by invasion of interior heat. This view is therefore satisfactory as far as it goes, and brings order out of the chaos of mountain phenomena. It has successfully directed geological investigation in the past and will continue to do so in the future.

But there still remains the question: "*What is the cause of the lateral pressure?*" The answer to this question constitutes the *physical theory*.

Thus far I suppose there is little difference of opinion. I have only tried to put in clear condensed form what most geologists hold. But henceforward there are the most widely diverse views and even the wildest speculations. But let us not imagine, on that account that we have made no progress in the science of mountain-origin. The *formal theory* already given is really for the geologist by far the most important part of the theory of mountain-origin. For I insist that for the geologist *formal* theories are usually more important than *physical* theories of geological phenomena. That slaty cleavage is the result of a mashing of strata by a force at right angles to the cleavage-planes, is of capital importance to the geologist, for it is a guide to all his investigations. To what property of matter this structure is due is of less importance to him, though of prime importance to the physicist. That the phenomena of the drift is due to the former existence of a moving ice-sheet is the one thing most important to the geologist, guiding all his investigations. Whether this ice-sheet was caused by geographical or astronomical changes is a question of wider but of less direct interest to him. So in the case of mountain ranges, the most important part of the theory is their origin by lateral pressure under the conditions given above. The *cause* of the lateral pressure, though still of extreme interest, is certainly of less immediate importance in guiding investigations.

PHYSICAL THEORIES.

The most obvious view of the cause of lateral pressure refers it to the *interior contraction of the earth*. This may be called the

"CONTRACTIONAL THEORY."

This theory is so well known that I will give it only in very brief outline. It assumes that the earth was once an incandescent liquid and has cooled and solidified to its present condition. At first it cooled most rapidly at the surface and must have fissured

by tension. But there would inevitably come a time when the surface being substantially cool and moreover receiving heat also from the sun, its temperature would be fixed or nearly so, while the incandescent interior would be still cooling and contracting. Such has probably been the case ever since the commencement of the *recorded* history of the earth. The hot interior now cooling and contracting more rapidly than the cool crust, the latter following down the ever shrinking nucleus would be thrust upon itself by lateral pressure with a force which is simply irresistible. If the crust were ten times, yea one hundred times more rigid than it is, it must yield. It does yield along the lines of greatest weakness, *i. e.*, along marginal sea-bottoms as already explained. As a first attempt at a physical theory, it seems reasonable, and therefore, until recently, has been generally accepted.

OBJECTIONS TO THE CONTRACTIONAL THEORY.

It is well known that American geologists have taken a very prominent part in the study of mountain structure and mountain origin. So much so indeed that the *lateral pressure theory* in the form given above and interior contraction as its cause, have sometimes been called the "American theory." It is also well known that my name, among others, especially Dana's, has been associated with this view. All I claim is to have put the whole subject, especially the formal theory, in a clearer light and more consistent form.[1] The formal theory I regard as a permanent acquisition. The contractional theory may not be so. It is natural, from my long association with it, that I should be reluctant to give it up. But I am sure that I am willing to do so if a better can be offered. We all dearly love our own intellectual children, especially if born of much labor and thought; but I am sure that I am willing, like Jephtha of old, to sacrifice, if need be, this my fairest daughter on the sacred altar of Truth. Objections have recently come thick and fast from many directions. Some of these

[1] "Theory of the Formation of the Great Features of the Earth's Surface." Am. Journal, Vol. 4, pp. 345 and 460, 1872, and also "Structure and Origin of Mountains," Vol. 16, p. 95, 1878.

I believe can be removed ; but others perhaps cannot in the present condition of science, and may indeed eventually prove fatal. Time alone can show. I state briefly some of these objections.

1. Mathematical physicists assure us that on any reasonable premises of initial temperature and rate of cooling of the earth, the *amount* of lateral thrust produced by iuterior contraction would be wholly insufficient to account for the enormous foldings.[1] Let us admit—surely a large admission—that this is so. But this conclusion rests on the supposition that the whole cause of interior contraction is *cooling*. There may be other causes of contraction. If cooling be insufficient, our first duty is to look for other causes. Osmund Fisher has thrown out the suggestion (a suggestion by the way highly commended by Herschel) that the enormous quantity of water vapors ejected by volcanoes and the probable cause of eruptions is not meteoric in origin as generally supposed, but is original and constituent water occluded in the interior Magma.[2] Tschermak has connected this escape of constituent water from the earth with the gaseous explosions of the sun.[3] Is it not barely possible that we may have in this an additional cause of contraction, more powerfully operative in early times but still continuing? See the large quantity of water occluded in fused lavas to be "*spit out*" in an act of solidification! But much still remains in volcanic glass which by refusion intumesces into lightest froth. Here then, is a second possible cause of contraction. If these two be still insufficient, we must look for still other causes before rejecting the theory.

2. Again: Dutton[4] has shown that in a *rigid earth* it is impossible that the effects of interior contraction should be concentrated along certain lines so as to form mountain ranges, because this would require a shearing of the crust on the interior. The yield-

[1] Cam. Phil. Trans. Vol. XII., Part II., Dec. 1873.

[2] Cambridge Phil. Trans. Vol. XII., Part II., Feb. 1875. Physics of the Earth's Crust, p. 87.

[3] Geol. Mag. Vol. IV., p. 569, 1877.

[4] Am. Jour. Vol. VIII., p. 13, 1874. Penn. Monthly, May, 1876.

ing according to him would be evenly distributed everywhere and therefore imperceptible anywhere. This is probably true, and therefore a valid objection in the case of an earth *equally rigid in every part.* But if there be a sub-crust layer of liquid or semi-liquid or viscous, or even more movable or more unstable matter, either universal or over large areas, as there are many reasons to think, then the objection falls to the ground. For in that case there would be no reason why the effects of general contraction should not be concentrated on weakest lines as we have supposed.

3. But again: it has been objected that the lines of yielding to interior contraction ought not to run in *definite* directions for *long distances*, but irregularly in *all* directions. I believe we may find the answer to this objection in the principle of flow of solids under very slow heavy pressure. The flow of the solid earth, under pressure in *many* directions, might well be conceived as being deflected to the direction of least resistance, *i. e.*, of easiest yielding.

4. But again: it will be objected that the amount of circumferential shortening necessary to produce the foldings of some mountains is simply incredible; for it would disarrange the stability of the rotation of the earth itself. According to Claypole, in the formation of the Appalachian range, the circumference of the earth was shortened eighty-eight miles and in the formation of the Alps seventy-two miles. Now this would make a decrease of diameter of the earth of twenty-eight miles in the one case and twenty-three in the other. This would undoubtedly seriously quicken the rotation and shorten the day. This seems indeed startling at first. But when we remember that the tidal drag is all the time retarding the rotation and lengthening the day and much more at one time than now, we should not shrink from acceptance of a counteracting cause hastening the rotation and shortening the day, and thus giving stability instead of destroying it. We must not imagine that there would be anything catastrophic in this readjustment of rotation. Mountains are not formed in a day nor in a thousand years. It requires

hundreds of thousands of years, or even millions of years—if physicists allow us so much.

The objections thus far brought forward, though serious, are by no means unanswerable. But there is one brought forward very recently which we are not yet fully prepared to answer and may possibly prove fatal.

5. *Level of No Strain*.—Until recently the interior contraction of the earth was considered only roughly and without analysis. It was seen that the surface was already cool and its temperature fixed while the interior was still hot and cooling; and therefore that the exterior must be thrust upon itself and be crushed. But the phenomena are really far more complex than at first appears. It is necessary to distinguish between two kinds of contraction to which the interior layers are subjected, viz., radial and circumferential. If there were radial contraction only, then undoubtedly every concentric shell as it descended into smaller space would be crushed together laterally. But there is for all layers, except the surface, also a circumferential contraction, and this would have just the opposite effect, *i.e.*, would tend to stretch instead of crush. Therefore wherever the decrease of space by descent is greater than the circumferential contraction, there will be crush, and where the circumferential contraction is greater than the decrease of space by descent, there will be tension and tendency to crack. There would be no *real* cracking, only because incipient cracks would be mashed out or rather prevented by superincumbent pressure. Where these two are equal to one another, there will be no strain of any kind. There is a certain depth at which this is the case. It is called the "*level of no strain*." To Mellard Reade is due the credit of first calling attention to this important principle.

Let us analyze the principle more closely. It is admitted that at the surface there is no contraction of any kind. It is also calculated that contraction of all kinds cease at depth of 400 miles. It is believed farthermore that commencing 400 miles below the surface and coming upward the contraction increases very slowly from zero to a maximum at the depth of 70 miles

and then decreases again more rapidly to zero at the surface. This is shown in diagram, Fig. 1. In this figure the curve represents the relative rate of contraction whether radial or circumferential of the several layers. We use it, however, only to represent the latter. For in considering the radial contraction, it is not the relative rate of the several layers that immediately concerns us, but their rate of *radial descent.* Now this is a *summation series* and therefore increases to the very surface, but at different rates of increase. The law of increase of radial descent as we come toward the surface is shown in diagram, Fig. 2[1] in which the rate of increase is greatest at seventy miles, just where the curve changes from concavity to convexity. If now we superpose these two diagrams the depth *a* at which the two curves,

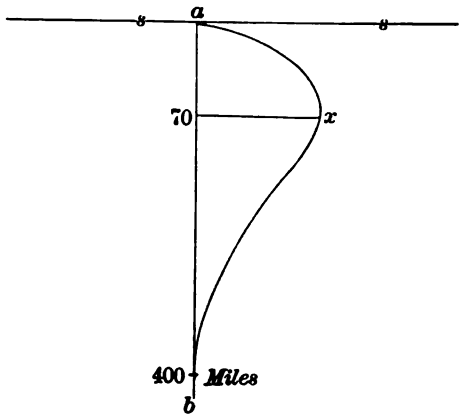

FIG. 1. *s s*=Surface; *a b*=depth along radius; *a x b*= curve of contraction.

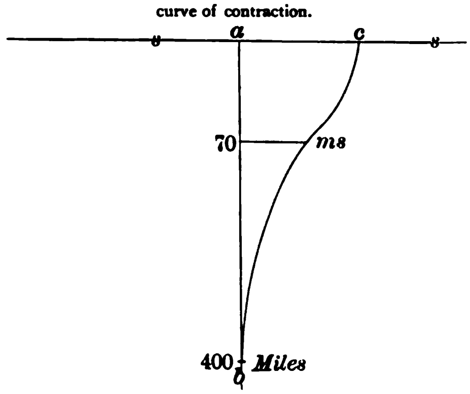

FIG. 2. *c b*=curve of radial descent.

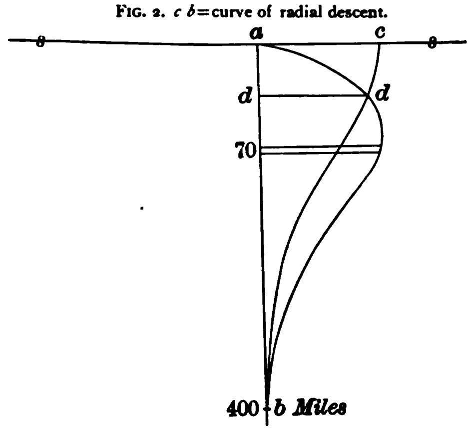

FIG. 3. *d d*=level of no strain.

[1] I have taken these figures from Claypole, but modified this one so as to make it a truer representation of the law.

viz., that of circumferential contraction and that of radial descent, intersect, is the level of no strain.

Now laborious calculations have been made by Davison, Darwin and Fisher to determine the depth of this level of no strain. All make it very superficial. Davison, taking an initial temperature of 7000° F., makes it five miles below the surface. Fisher, on the same data, only two miles, and with an initial temperature of 4000° only *0.7* of a mile. It is easy to see that if this be true, the amount of lateral thrust must be small indeed.

Now undoubtedly there is a true principle here which must not hereafter be neglected, but it is almost needless to say that these quantitative results are in the last degree uncertain. The calculations are, of course, based on certain premises. These are a uniform initial temperature of say 7000° F., a time of cooling, say 100 or 200 millions of years, and a certain rate of cooling under assumed conditions. The depth of the level of no strain increases with the time and is still going downward. In a word, in a question so complex both mathematically and physically and in which the data are so very uncertain, every cautious geologist, while freely admitting the soundness of the principle, will withhold assent to the conclusions. Huxley has reminded us that the mathematical mill, though a very good mill, cannot make wholesome flour without good wheat. It grinds indifferently whatever is fed to it. It has been known to grind peas cods ere now. It may be doing so again in this case. Let us wait.

But besides withholding assent and waiting for more light, I may add that these calculations, of course, go on the supposition that the whole contraction of the earth is due to loss of heat; but as we have already said, it may be due also to loss of constituent water. This would put an entirely different aspect on the subject.

ALTERNATIVE PHYSICAL THEORIES.

I have given the objections to the contractional theory frankly and I think fairly. They are undoubtedly serious. Let us see what has been offered it its place.

I. READE'S EXPANSION THEORY.

This, the most prominent among alternative theories, was first brought forward in Mr. Reade's book on "Origin of Mountain Ranges." Although I have carefully read all that Mr. Reade has written on the subject, I find it difficult to get a clear idea of his views. But, as I understand it, it is in outline as follows: (1) Accumulation of sediments off shore and isostatic subsidence of the same. (2) Rise of isogeotherms and heating of the whole mass of sediments and of the underlying crust in proportion to the thickness of the sediments. (3) *Expansion* of the whole mass in proportion to the rise of temperature. If there were no resistance, this expansion would be in all directions (cubic expansion). (4) But since the containing earth will not yield to expansion laterally, this lateral expansion is satisfied by *folding*, and this in turn produces *vertical upswelling*. Thus the whole *cubic expansion is converted into vertical expansion*, which is therefore three times as great as the linear expansion in any one direction. (5) Elevation would of course anyhow be greatest along the line of thickest sediment; but this by itself would not be sufficient to produce a mountain. (6) But farther—and here the theory is more obscure —there is a concentration of the effects of expansion, along a comparatively narrow line of thickest sediment, by a *flow* of the hydrothermally plastic or even liquid mass beneath, *toward* this central line and then *upward* through the parted strata, folding these back on either side and appearing at the crest as the granitic or metamorphic axis. (7) In his latest utterances he seems to adopt the view of Reyer, viz., that the uplifted strata slide back down the slope, producing the enormous crumpling so often found, and exposing a wider area of granite axis. (8) From the same liquid mass which lifts the mountain, come also the great fissure eruptions and the volcanoes.

Mr. Reade makes many experiments to determine the linear expansion of rocks, and he thinks that these experiments show that when cubic expansion is converted into vertical expansion and this again concentrated along a line one-fourth to one-fifth the whole breadth of the expanding mass, it would explain the

elevation of the highest mountains. But still he seems uncertain if it be enough. In fact, he declares that if it were not for another factor yet unmentioned, he probably would never have brought forward the theory at all.

(9) This factor is *recurrency of the cause and accumulation of the effects*. And here the previous obscurity becomes intensified. I have read and re-read this part without being able wholly to understand him. He seems to think that when expansion had produced elevation, the mountain thus formed would not come down again by cooling and contraction; but on the contrary would *wedge up by normal faulting and set in its elevated position*. Afterward, by new accumulation of heat, another elevation and setting would take place and the mountain grow higher, and so on indefinitely, or until the store of heat is exhausted. Therefore he characterizes his theory as that of "*Alternate expansion and contraction*," or again as that of "*Cumulative recurrent expansion*."

Such is a very brief, perhaps imperfect, but I hope fair outline of Reade's theory. It seems to me that there are fatal objections to it. These I now state.

Objections.—1. The first is *inadequacy* to account for the enormous foldings of the mountains especially when there is no granite axis to fold back the strata. It is true that Mr. Reade makes comparison between his own and the contractional theory in this regard, and seems to show the much greater effectiveness of his own. This may be true if we accept his premises and compare *equal areas* in the two cases. But the contractional theory *draws from the whole circumference* of the earth and *accumulates* the effects on one line, while in Reade's theory the expansion is, of course, very *local*.

2. But the fatal objection is that brought forward by Davison. It is this: sedimentation cannot, of course, increase the sum of heat in the earth. Therefore the increased heat of the sediments by rise of isogeotherms, *must be taken from somewhere else*. Is it taken from below? Then the radius below must contract as much as the sediments expand and therefore there will be no elevation. Is it taken from the containing sides? Then

the sides must lose as much as the sediments gain, and therefore must contract and make room for the lateral expansion, and therefore there would be no folding and no elevation. I do not see any escape from this objection.

Thus it seems that Reade's theory cannot be accepted as a substitute. Is there any other?

II. DUTTON'S ISOSTATIC THEORY.[1]

Dutton's discussion of isostasy is admirable, but his application of it to the origin of mountains is weak. The outline is as follows:

Suppose a bold coast line, powerful erosion and abundant sedimentation. The coast rises by unloading and the marginal sea-bottom sinks by loading. Now if isostasy is perfect, there will be no tendency to mountain formation. But suppose a piling up of sediments, but—on account of earth rigidity—without immediate compensatory sinking, and a cutting down of coast land without compensatory rising. Then *there would be an isostatic slope toward the land.* And the accumulated and softened sediments would *slide landward, crumpling the strata and swelling them up into a mountain range.*

The fatal objection to this view is that complete isostasy is necessary to renew the conditions of continued sedimentation and therefore to make thick sediments, otherwise the sediments quickly rise to sea-level and stop the process of sedimentation at that place. But it is precisely a *want* of complete isostasy which is necessary to make an isostatic slope landward. Dutton refers to Herschel as having suggested a similar cause of strata crumpling and slaty cleavage[2]; but the principles involved in the two cases are almost exactly opposite. Herschel supposes sediments to slide down steep *natural* slopes of sea-bottoms and therefore *seaward.* Dutton supposed sediments to slide *up* natural, though *down* isostatic slopes, *landward.* Herschel's is a theory of strata-

[1] Phil. Soc. of Washington, Bull. Vol. XI, pp. 51–64, 1889.

[2] Phil. Mag., Vol. 12, 197, 1856.

crumpling and slaty cleavage; Dutton's a theory of mountain formation.

There has been no attempt to carry this idea of Dutton's to quantitative detail. It was probably thrown out as a suggestion in mere despair of any other explanation, for he had already repudiated the contractional theory. But the least reflection is sufficient to convince that such slight want of complete isostatic equilibrium as may sometimes occur would be utterly inadequate to produce such effects.

III. REYER'S GLIDING THEORY.[1]

Prof. Reyer has recently put forward certain views fortified by abundant experiments on plastic materials. His idea in brief seems to be this: Strata are lifted and finally broken through by up-rising fused or semi-fused matters and these appear above as the granitic axis. As the axis rises, the strata are carried upward on its shoulders, until *when the slope is sufficiently steep the strata slide downward crumpling themselves into complex folds* and exposing the granitic axis in width proportioned to the amount of sliding.

No doubt there is much value in these experiments of Reyer, and possibly such gliding does indeed sometimes take place in mountain strata and some foldings may be thus accounted for. But the great objections to this view are (1) that there is no adequate *cause* given for the *granitic uplift*, and (2) that it utterly fails to account for the complex foldings of such mountains as the Appalachian and Coast Range *where there is no granite axis at all*. Reade, indeed, holds that the Piedmont region is the granite axis of the Appalachian, and that the original strata of the eastern slope are now buried beneath the sea. But American geologists are unanimous in the belief that the shore line of the great interior Palæozoic sea was but a little east of the Appalachian crest and the sea washed against land of Archæan rocks extending eastward from that line.

[1] Nature, Vol. 46, p. 224, 1892, and Vol. 47, p. 81, 1892.

CONCLUSION.

After this rapid discussion of alternative theories in which we have found them all untenable, we return again to the contractional theory, not indeed with our old confidence, but with the conviction that it is even yet the best working hypothesis we have.

JOSEPH LE CONTE.

ON THE MIGRATION OF MATERIAL DURING THE METAMORPHISM OF ROCK-MASSES.

THE researches of numerous geologists during the last two decades have placed at our disposal a large amount of information respecting the metamorphism of rocks, and from the facts thus collected we are now in a position to draw conclusions which we may expect to have a wide application. The important changes that affect the character of rock-masses divide roughly into two classes.

First, there are those dependent on meteoric agencies. These changes, though not necessarily superficial in the ordinary sense, are due in the first place to the action of circulating waters in communication with the atmosphere, and as a rule they involve the addition or subtraction of various ingredients or the transference of material from one place to another. The ordinary "weathering" effects illustrate the removal of alkalies and silica, the addition of water, oxygen, carbonic acid, etc. We must also include the processes which have given rise to many crystalline limestones and quartzites, serpentine-rocks, dolomites, ironstones, and jaspers, and even (as appears from Van Hise's researches in the Penokee region) some mica-schists and fine-grained gneisses. The characteristic of almost all these transformations is that they are metasomatic as well as metamorphic.

Secondly, we have those transformations more usually understood by the term metamorphism : viz., dynamic metamorphism, due to high pressure operating upon rock-masses, and thermal metamorphism, due to high temperature, whether produced by an intrusion or by the mechanical generation of heat. In these various cases of metamorphism proper, metasomatism is rather the exception than the rule. I shall deal here with thermal metamorphism only, and shall draw my data chiefly from the rocks surrounding the large igneous intrusions of the English Lake District, investigated by Mr. Marr and myself, but the conclusions are confirmed in other areas.

Metasomatic changes are known to take place during thermal metamorphism as regards the *volatile* constituents of the rocks affected. A (usually partial) loss of water and the elimination (under proper conditions) of carbonic acid from carbonates are instances of this; a more special case is the accession of boric and hydrofluoric acids near the contact of metamorphosed rocks with certain acid intrusives. Several observers have recorded a transference of other materials (silica and soda) from an invading igneous magma to the neighboring rocks, but such a phenomenon seems to be of uncommon occurrence, and to be confined to the immediate vicinity of the contact. Apart from the exceptions noted, there is every reason to believe that thermal metamorphism involves no alteration in the bulk-analysis of the rocks affected. Whatever part water may play in the various chemical changes that are set up, it does not (as in atmospheric metamorphism) act as a medium to transfer material to or from the rocks in question.

I believe that we can go further, and assert that within the mass of a rock undergoing thermal metamorphism any transference of material (other than volatile substances) is confined to extremely narrow limits, and consequently that, for a given temperature of metamorphism, the mineral formed at any point depends only on the chemical composition of the rock-mass within a certain very small distance around that point. Illustrations of this principle, as stated in the latter form, are familiar to all who have studied cases of "contact metamorphism":[1] they are very striking when some of the constituent substances of the original rock were, by weathering or otherwise, locally aggregated prior to metamorphism. By studying such cases we can not only verify the principle here laid down, but also arrive at an estimate of the actual limits within which interchange of material has taken place.

An excellent test-case is afforded by rocks containing calcite. It is well known that impure calcareous rocks are readily metamorphosed by heat into rocks rich in lime-silicates, with total

[1] Compare Bull. Geol. Soc. Amer. (1891) vol. iii., pp. 16–22.

elimination of the carbonic acid, while pure limestones or dolomites, under the same conditions, merely recrystallize without chemical change. In other words, the carbonates are decomposed in thermal metamorphism only in the presence of silica in some available form to take the place of the carbonic acid. Interesting illustrations of this are given by some of the rocks which have come under our notice.[1] The Strap granite in Westmoreland metamorphoses certain basic lavas containing amygdules of various dimensions, many of which were occupied, prior to the metamorphism, by calcite. Near the granite the smallest of these calcite-amygdules are converted into various silicates rich in lime, the silica having been derived from decomposition-products lining the original vesicles or from the immediately adjacent portion of the rock. In the larger metamorphosed amygdules, on the other hand, only the outer layers are transformed into lime-silicates, the interior still consisting of calcite; which, however, has recrystallized during the metamorphism, as is proved by its moulding the silicates and being penetrated by needles of actinolite, etc. Analogous appearances characterize veins and lenticles of calcite in shales and the converse case of argillaceous nodules imbedded in pure limestones and dolomites. The conclusion is that carbonic acid is displaced from the calcite only when there is in the immediate neighborhood either free silica or some substance capable of furnishing silica. Where calcite and quartz have recrystallized side by side in a metamorphosed rock, they are always separated by some one or more lime-bearing silicates, but their distance apart may be very small, and we deduce that the migration of silica to take the place of carbonic acid has been restricted to extremely narrow limits. In some highly altered rocks the distance is not more than one-twentieth of an inch.

The limit of migration of material no doubt increases with the temperature of metamorphism. This is well illustrated by some calcareous ashes or tuffs. At a considerable distance—say a thousand yards—from a large granite intrusion, the carbonic

[1] See especially Quart. Journ. Geol. Soc. (1893) vol. xlix., pp. 359–371.

acid is entirely expelled only from very fine-grained mixtures of calcareous and ashy materials: approaching the contact, the complete decomposition of the calcite is found to extend to successively coarser-grained rocks. Another line of inquiry is offered by the texture of the metamorphosed rocks themselves, of whatever lithological nature, in a district of metamorphism surrounding a large igneous intrusion. The size of the individual crystals of secondary minerals increases towards the contact with the intrusive rock: this may be taken to indicate that the migration of material within the mass of a rock undergoing metamorphism has more latitude when the temperature is higher. For various reasons, however, it would be unsafe to found numerical results upon such observations. The crystals of certain metamorphic minerals attain to considerable dimensions by virtue of their power of enclosing a large amount of foreign material; others, again, can apparently push aside solid impurities to make room for their own growth. The texture of the metamorphic rocks examined is still, however, in general accord with the conclusions reached by other methods of inquiry.

The question naturally arises whether the limit of migration of material is the same for different substances. On this point we have but little information. Among the various types of "spotted" rocks described in aureoles of metamorphism is one in which the spots are simply spaces free from the secondary brown mica abundant in the general mass of the metamorphosed rock. Since the iron compounds in the rock must originally have had a generally uniform distribution, the phenomena of the spots indicate a movement of ferrous oxide, and the radius of the spots gives a measure of the extreme limit of such movement. In the cases examined this is about one-twentieth of an inch, and we may infer that the greatest distance of migration of ferrous oxide has been about the same as that of silica at a similar temperature.

Not to insist unduly upon precise estimates, these and similar observations certainly tend to show that in thermal metamorphism no interchange of material takes place except between

closely adjacent points. The law that, apart from volatile constituents, the total chemical composition remains unchanged is true not only of the rocks in bulk, but of any individual cubic inch of the rocks. This might be followed out into various corollaries, of which I note only one, viz., that the greatest variety of metamorphic minerals is to be found in rocks which were the most heterogeneous prior to metamorphism. Such rocks are breccias and fault-breccias, etc., and especially basic igneous rocks more or less weathered before being metamorphosed.

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THE CORDILLERAN MESOZOIC REVOLUTION.

CERTAIN features connected with the occurrence of plutonic rocks on the western side of America suggest hypotheses which have an important bearing upon our general conceptions of the structural development of the continent. These features are but imperfectly and very partially recorded thus far in geological literature, owing to the vastness of the field and the meagre amount of investigation which has been devoted to it. Yet enough facts have been accumulated to have impressed the writer that they point to generalizations which have not yet been fully presented for the consideration of students of continental problems. To formulate these generalizations is the object of this brief note. It is not the purpose of the writer to add to the record of facts so much as to connote the more important of them and to suggest their cumulative significance.

The researches of Richardson[1] and Dawson[2] on the coast and islands of British Columbia have shown that the Cretaceous rocks of that region, ranging from the *Aucella* bearing horizon (Neocomian) to the Chico, repose upon a profoundly eroded complex of granite and metamorphic rocks. The disturbances which have affected these Cretaceous strata since their deposition have been of a local rather than of a regional character. They lie upon the old basement usually in but little disturbed attitudes, or are inclined at low angles, though occasionally they are faulted or sharply folded along certain lines of post-Cretaceous movement. The same condition seems to generally characterize the more elevated early Cretaceous rock of the British Columbian interior along the cañon of the Fraser river. Jurassic rocks have been described from British Columbia, but the Geological Survey of Canada has since come to the conclusion that these rocks are

[1] Reports of Progress, Geol. Survey of Canada, 1871–2, 1872–3, 1873–4, 1874–5, 1876–7.

[2] Report of Progress, Geol. Survey of Canada, 1878–9. Annual Report (New Series) Vol. II., 1886. Geol. Survey of Canada, Report B.

Cretaceous.[1] If the Jurassic exists on the west coast of British Columbia, it must occupy very limited areas or be involved in the pre-Cretaceous metamorphic complex. The fossils collected in the less altered portions of this complex by Richardson and Dawson, show the presence of Triassic and Carboniferous formations, but no undoubted Jurassic forms have yet been detected. It therefore seems that the erosion to which the region was subjected prior to the deposition of the Cretaceous was effected in Jurassic time. As Dawson has shown,[2] this erosion was of longer duration in the southern part of the province than in the northern, and the transgression of the Cretaceous sedimentation was from north to south.

The further studies of Dawson upon the pre-Cretaceous complex of granite and metamorphics have been fruitful of most interesting and important results. Prior to his researches the granite (and granite-gneisses) of the region were generally regarded as the equivalent of the Laurentian of the east. It was shown,[3] however, by him that the basement upon which the now metamorphic sedimentary and volcanic strata of the Vancouver series (Triassic, with probably some Carboniferous), was deposited is non-existent, and has been replaced by an immense mass of intrusive granite, which has absorbed by fusion all rocks below the present remnants of the Vancouver series, and has invaded the latter after the manner of an irruptive magma. This post-Triassic granitic batholite is of enormous dimensions. In the fall of 1890 the writer had an opportunity of examining it cursorily for a distance in a straight line of over five hundred miles, in and out of the fiords of the coast from Burrard Inlet to Alaska; and the granite is known to extend far northward into that territory. Its width may be placed at from sixty to one

[1] Sketch of the Geology of British Columbia, by G. M. Dawson, Geol. Mag., April and May, 1881.

[2] Am. Jour. Sci., Vol. xxxix., March, 1890.

[3] Annual Report (New Series), Vol. ii., 1886, Geol. Survey of Canada, Report B, pp. 10-13.

hundred miles. In the portion examined there are several masses or belts of schistose metamorphic rocks which have been sunk down into the granite, but they form a small proportion of the entire complex. The granite varies somewhat in mineralogical composition, texture, and structure, and is often distinctly gneissic locally. In places it is essentially hornblendic, in others it is micaceous. Notwithstanding these variations, which are common in most large granite masses, the granite seems to be a unit throughout, and the mass is certainly a very important factor in the epeirogeny of the west coast of America. Even should it be discovered by the closer scrutiny which science will certainly demand, that there are portions of an older granite terrane to be discriminated from the general mass, the conclusion will not be invalidated, that in the interval between the deposition of Triassic strata and the deposition of lower Cretaceous, the earth's crust was in this region invaded by an immense batholitic magma, hundreds of miles in extent, which absorbed a large part of the pre-Triassic basement, as well as a portion of the Triassic rocks themselves. This invasion of the crust by the British Columbian batholite seems to have conditioned a general and pronounced elevation of the coast. For the erosion which intervened before the deposition of the Cretaceous was possessed of a vigor only born of lofty mountains, removing the upper crust and cutting down deep into the congealed granite. The Cretaceous rocks were littoral deposits at the base of these lofty mountains. Thus was a great revolution wrought in the geology and physiography of the west coast of British Columbia in the interval between the Triassic and Cretaceous times.

Little is definitely known of the geology of the Olympic Mountains, but it is probable that the conditions which prevail on Vancouver Island, which is the northern extension of the range, hold good here, the Cretaceous rocks of the coast reposing upon the lower flanks of mountains which consist of a complex of granite and metamorphic rocks. These mountains are probably the least known portion of the United States, and they are mentioned here simply to indicate that important evidence

bearing upon the phenomena here discussed is likely to be found in that region.

In southern Oregon, on the line of the Southern Pacific Railway, the writer has on several occasions observed the eruptive contact of an extensive granite mass against sedimentary strata which have been mapped as "Auriferous slates," which are probably early Mesozoic or Carboniferous in age. The intrusion of the granite into the sedimentary rocks is unquestionable, the relations being well exhibited in the excellent exposures afforded by the railway cuttings.

In California the statements of Whitney[1] and the more recent writings of the geologists of the U. S. Geological Survey, Diller, Becker, Turner, and Lindgren, and of Mr. H. W. Fairbanks, seem to leave no room for doubt that a great part, probably the greater part, of the granitoid rocks of the Sierra Nevada is of Mesozoic age, and has invaded the now more or less altered sedimentary and volcanic rocks known as the "Auriferous slates," which range in age from the Silurian up to the Jurassic.

Here again we have clearly to deal with a granitic batholite which must, by absorption or otherwise, have replaced a large portion of the preëxisting lower rocks in the region affected. From the facts recorded by able and critical observers, this conclusion holds, notwithstanding the probability that there may also be remnants of an older granite to be discriminated from the Mesozoic mass. In the southern Sierra, as Becker has, with wise caution, pointed out, we approach the region of Archæan granite known in the Grand Cañon section. It would therefore be not at all remarkable to find these more ancient granites involved with the newer in the Sierra Nevada. But their presence could not affect the important fact of an invasion of the crust during middle Mesozoic time by an immense granitic batholite, which invasion without doubt had much to do with the metamorphism of the strata which survived the upward progress of the magma into the crust.

Here again the development of the batholite seems to have

[1] Geology of California, Vol. I. Auriferous Gravels.

conditioned the uplift and wide-spread disturbance which is freely recognized in geological literature as having occurred at the close of the Jurassic. Again we have, as in British Columbia, a wonderful dissolving of the ancient *status quo*, a revolution of no mean import, whether regarded merely as an historical event or in its bearing upon the general principles of epeirogeny. The important feature which distinguishes the group of facts observed in the Sierra Nevada from those in British Columbia is that in the former we have the Jurassic a part of the great assemblage of rocks invaded by the granite while in British Columbia these rocks are not known to exist. This difference, taken together with the probable fact that the pre-Cretaceous denudation of the Sierra was less profound than that of British Columbia, suggests a progressive development of the batholitic condition from north to south, so that the disturbance was felt somewhat later in California, although it was part, doubtless, of the same great subcrustal process.

In the Coast Ranges of California we have much less precise information than in the case of the Sierra Nevada. Analogous conditions seem to be indicated by the information at hand. There are areas of granite and metamorphic rocks which have been subject to great denudation prior to the deposition of the Cretaceous. No rocks of older age than Cretaceous are known to rest upon the worn surface of this complex. Carboniferous fossils have recently been found by Mr. Fairbanks in the Santa Ana Range[1] in a series of rocks into which the granite of the region has been injected. The same geologist informs us of the intrusion of the granite of the Gavilan Range[2] into the Coast Range metamorphics, and of similar relations in the Trinity Mountains in the Northern part of the state.[3] The writer, also, has observed that the granite of the Santa Cruz Range is intrusive in the limestone of the metamorphic complex. Mr. Fairbanks is of the opinion that generally the

[1] Am. Geologist, vol. xi., Feb., 1893.

[2] Loc. cit.

[3] Am. Geologist, March, 1892.

granite of the Coast Ranges is the equivalent of that of the Sierra, but direct evidence of its intrusion into Triassic or Jurassic strata has not yet been adduced. All that can safely be asserted at present, in the opinion of the writer, is that in the Coast Ranges there is a pre-Cretaceous complex of granite and metamorphic rocks analogous to that of the Sierra Nevada; and that there is no evidence yet recorded which is adverse to Mr. Fairbank's correlation of the granites of the two regions.

In Mexico the official map shows conditions which resemble those of the Sierra Nevada. Emerging from beneath the volcanic sheets, or the mantles of Tertiary or Quaternary formations there are, along the western side of the Republic, numerous masses of granite rocks with associated metamorphics. In these metamorphic rocks are occasional patches of Jurassic and Triassic, conservatively limited in the mapping doubtless to the actual areas where fossils have been found to so determine their age. These small patches of known Jurassic and Triassic age are suggestive of the proximate limit in age of the metamorphic series, and yielding to analogy we may be allowed to *suppose* that the granite bears a relation to the Mexican metamorphics similar to that exhibited in the Sierra Nevada of California.

In South America Steinmann[1] calls attention to the important fact of the invasion of the Mesozoic strata of the Cordillera by truly granitic and dioritic rocks. Karsten,[2] also, informs us that in Columbia, Venezuela and Ecuador the Jurassic are the oldest sedimentary rocks, but have been found at only one locality, while the Cretaceous and Tertiary are abundantly developed; and that the underlying basement upon which the Cretaceous rests is largely granitic. Putting Steinmann's and Karsten's information together we seem clearly to have the conditions of British Columbia and California repeated as to the development of a granitic batholite in the Cordilleran belt in pre-

[1] Am. Naturalist, Oct. 1891.

[2] Geologie de l'Ancienne Colombie Bolivarienne, Nouvelle Grenada et Ecuador, par Hermann Karsten, Berlin.

Cretaceous Mesozoic time, followed by continental uplift and great denudation.

From the facts above cited certain conclusions seem to be warranted which may be presented in the form of hypotheses for future examination:

(1) The pre-Cretaceous Mesozoic revolution which has been freely recognized by nearly all Californian geologists was not limited to the western United States, but affected the entire extent of the Cordilleran belt from Alaska to South America.

(2) It is not clear that the revolution was strictly synchronous in all portions of the Cordilleran belt which have been affected. It may have been progressive, and have extended through the time from the close of the Triassic to the close of the Jurassic so as to obliterate the Jurassic seas earlier in some regions than in others.

(3) An essential feature of the revolution was the development of batholitic magmas which invaded the crust, replaced large portions of it, and eventually congealed as plutonic rock of a prevailingly rather acid character.

(4) The development of the batholite, or batholites, was followed or accompanied by continental uplift.

(5) The complex of invading granite and consequent metamorphics is analogous to that of the Archæan and indicates that the conditions which are commonly recognized as Archæan are not peculiar to rocks of that age.

By way of addendum to this brief note it should be remarked that the irruption of granite in South America did not wholly cease with the Mesozoic revolution. Farther south than the countries which have been mentioned, in the Cordillera of the Argentine Republic, Stelzner has shown that this phase of crustal development continued through into the Tertiary. After a narration and discussion of his facts he formulates the following conclusion:

"So mit bleibt denn nur noch die Annahme übrig, dass die als Granite, Syenite und Diorite zu bezeichnenden Andengesteine eruptive Gebilde sind, die theils nach der Jura- und Kreidezeit,

z. Th. sogar erst nach der in der Tertiärzeit erfolgten Ablagerung der buntscheckigen Andesittuffe im gluthflüssigen Zustande emporgestiegen sind und diejenigen Lagerungsverhältnisse eingenommen haben, unter welchen wir sie heute beobachten können."[1]

ANDREW C. LAWSON.

BERKELEY, July 15, 1893.

[1] Beitrage zur Geol. und Palaeont. der Argentinischen Republic, I. Geol. Theil, p. 207.

THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

III. SKETCH OF THE PRESENT STATE OF KNOWLEDGE CONCERNING THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.[1]

WITHOUT attempting to distinguish critically between the different types of the basic rocks occurring in the Lake Superior region, it will be sufficient for the present to call attention to some of the work done on them, more especially with reference to their microscopical examination. It will not be necessary to refer to all of the articles in which the "traps" of the region have been more or less briefly mentioned, as it will serve our present purpose to allude only to the most important papers on the subject, and to outline, where advisable, the descriptions of the most important rocks as given by various authors. Professor Irving[2] has discussed the theories held by some of the writers with respect to the origin of the traps, but since these, when they differ from the generally accepted theory of an igneous origin for the rocks in question, are found to be opposed to the facts observed, it would be unprofitable to discuss them further. There can be no doubt but that all of the basic, massive rocks found in dykes and beds in the Lake Superior region are truly igneous.

Douglass Houghton[3] first called attention to the wide-spread occurrence of traps around Lake Superior in his Fourth Annual Report as Geologist of Michigan. He identified knobs, dykes and flows of trap, but was unable to distinguish between the numerous varieties of the rock. His observations related principally to the traps in the Archæan and Keweenawan areas in Michigan.

[1] This Journal, Vol. I., p. 433.

[2] The Copper-Bearing Rocks of Lake Superior. Monographs U. S. Geological Survey, Vol. V., p. 7.

[3] Dated 1841. Reprint in Memoir of Douglass Houghton, by Alvah Bradish, Detroit, 1889, pp. 167–168, and 176–182.

Following Houghton, Messrs. Foster and Whitney[1] made an examination of the copper and iron regions of Michigan under the direction of the United States government. In their report on the copper lands, they described briefly the occurrences of dykes and flows of traps in the copper-bearing rocks of the south shore of the lake. Among them they distinguished compact, amygdaloidal, porphyritic, epidotic and brecciated varieties (pp. 69 and 70). In Part II. of the report, in their description of the iron region, they refer to the large dykes in the Animikie rocks on the north shore of the lake (pp. 12–13), and to the dykes of diabase cutting the Archæan schists in the neighborhood of Marquette, Michigan (pp. 18 and 39). They also gave a recapitulation of the characteristics of the traps of the entire region (pp. 85–94), with their chemical and mineralogical composition.

At about the same time that Messrs. Foster and Whitney were engaged in their survey of the copper and iron rocks, Dr. D. D. Owen,[2] with his assistants, was employed in making a geological reconnoissance of the states of Wisconsin, Iowa, and Minnesota. Messrs. D. D. Owen, J. G. Norwood, B. F. Shumard, Col. Whittlesey, and Major R. Owen examined a much larger area than did Messrs. Foster and Whitney, and were therefore not able to give as much detailed description of the rocks observed as the last named geologists succeeded in doing. They, however, mention the occurrence of sheet and dyke gabbros in Wisconsin, and of dyke gabbros in the Animikie of Minnesota.

Following these geologists came many others who examined the Lake Superior region in more or less detail, but added little to the knowledge of the trap rocks of the district, until, in 1871, Professor R. Pumpelly[3] published a paper on "The Paragenesis and Derivation of Copper and its Associates on Lake Superior," in which he described the melaphyres and other basic rocks associated with the copper on Keweenaw Point. After Pumpelly a number of geologists visited the region, but they devoted their

[1] Report on the Geology and Topography of a Portion of the Lake Superior Land District, Part I. Washington, 1850. Part II., Washington, 1851.

[2] Report of a Geological Survey of Wisconsin, Iowa, and Minnesota. By D. D. Owen. Philadelphia, 1852, pp. 142–164, 285, 304–306, 342–417.

[3] Am. Jour. Sci. (3) II., 1871, p. 188.

time principally to the discovery of the relations existing between the several rocks, and made no efforts to divide these into their varieties.

With the establishment of the surveys of Minnesota, Michigan, and Wisconsin, however, an attempt was made to classify with scientific accuracy the basic rocks of these three states. Kloos[1] had already discovered the gabbro of Duluth and had identified a melaphyre from the same place, but had made no very exact determination of either. Among the geologists on the Michigan and Wisconsin surveys, Messrs. Julien, Wright, Wichman, Pumpelly and Irving examined microscopically the rocks of the Huronian and the Keweenawan series of Wisconsin, and of the Archæan, Huronian and Keweenawan of Michigan, and among the descriptions of these rocks which they give may be found very exact accounts of the characteristics of the diabases, gabbros and other basic eruptives of the region.

Messrs. A. A. Julien[2] and C. E. Wright,[3] as early as 1873, mentioned quite fully the greenstones and traps of the Archæan and of the iron-bearing formations in Michigan. The former writer identified many massive and schistose rocks to which he gave the name of diorite, since he found in them hornblende, but no augite. Mr. Wright likewise discovered hornblende rocks which he evidently regarded as original, since he calls them all diorites. Mr. Wright's determinations are the first ones based upon microscopical observations of Lake Superior rocks. Messrs. Brooks[4] and Pumpelly[5] contented themselves with macroscopic examinations of the basic rocks of the iron and copper-bearing series in this state, and in this way distinguished diorites, melaphyres and amygdaloids, while Mr. Marvine[6] divided the

[1] J. H. KLOOS: Geologische Notizen aus Minnesota. Zeits. d. deutsch. geol. Gesell. XXIII., 1871, p. 417. Trans. by N. H. Winchell, 10th Ann. Rep. Geol. and Nat. Hist. Survey of Minnesota, for 1881, p. 193.

[2] A. A. JULIEN: Geological Survey of Michigan, Vol. II., 1873, Appendix A, p. 41.

[3] C. E. WRIGHT: Ib. Appendix C, p. 213–231.

[4] T. B. BROOKS: Geological Survey of Michigan, Vol. I., 1873; Part I., Iron-Bearing Rocks, pp. 99–104.

[5] R. PUMPELLY: Part II., Copper District, Ib. pp. 7–16.

[6] A. R. MARVINE: Part II., Copper District, Ib. pp. 95–116.

rocks of the Eagle River section of Keweenaw Point into greenstone or fine-grained diorites, feldspathic traps or coarse grained diorites, and traps, including the melaphyres and amygdaloids.

Before the publication of the reports of the Wisconsin survey, Messrs. Streng and Kloos[1] communicated the results of their examination of certain Keweenawan rocks occurring in Minnesota and in Wisconsin about the head of Lake Superior. Streng, who did the microscopical work of the investigation, recognized among his specimens melaphyres, augite-diorites, quartz-diorites and a hornblende-gabbro to which reference has already been made in a former article.[2] Pumpelly[3] also had devoted his attention to the rocks of the copper series. He studied more particularly the fine and coarse-grained diabases and melaphyres of Keweenaw Point.

With the publication of Volume III. of the Geological Survey of Wisconsin a more general classification of the Keweenawan rocks of Northern Wisconsin and of Keweenaw Point in Michigan was given by the same author.[4] He distinguished among them diabases, hornblende and orthoclase-gabbros, melaphyres, augite-diorites and porphyrites, the characteristics of which will be mentioned when the discussion of the diabases and gabbros of Keweenawan age is taken up. In the same volume Irving described the rocks of the Huronian of Wisconsin, among which he found gabbros (p. 147), and those of the Keweenawan in the same state (pp. 168 to 193). The hornblende-gabbros and the augite-diorites of Pumpelly he regarded as altered gabbros and diabases, and not as original hornblende rocks. Julien[5] also gave a very excellent account of the microscopic appearance of two olivine-diabases

[1] A. STRENG and J. H. KLOOS: Ueber die Krystallinischen Gesteine von Minnesota in Nord Amerika. Neues Jahrb. f. Min., etc., 1877, pp, 31, 113, 225.

[2] This Journal, Vol. I., p. 447.

[3] R. PUMPELLY: Metasomatic Development of the Copper-Bearing Rocks of Lake Superior. Proc. Am. Acad. of Arts and Sciences, 1878, XIII., Part II.. pp. 253-309.

[4] Geology of Wisconsin, III., 1880, p. 29.

[5] A. A. JULIEN: Microscopic Examination of Eleven Rocks from Ashland county Wisconsin. Geol. of Wisconsin, III., 1880, p. 224.

from Ashland county, Wisconsin; and Wichman[1] published a classification of Huronian rocks based on their microscopical examination. Wichman divided the massive basic rocks into diabases, coarse-diabases and diorites. The only other microscopical work done in connection with the Wisconsin Survey is that by the late C. E. Wright, published in the second volume of the reports. In this Mr. Wright[2] mentioned the occurrence of a diorite containing augite in the bed of Black river.

Further, Dr. Wadsworth,[3] in his discussion as to the origin of the jasper and iron-ores of the Marquette region describes briefly the microscopic features of many of the intrusive knobs that are so prominent a feature in the topography of the district. These are declared to consist largely of diabase and coarse basalt, both massive and slightly schistose.

The investigation of the basic rocks of the region had by this time been sufficiently exact, and the number of specimens examined was large enough to give an idea of the characters of the commonest types occurring there, but these investigations had been undertaken by so many different geologists that no exact correlation between the various varieties discovered was possible. No classification of these could be accomplished until some had examined specimens from all the different localities and had compared them with one another. This work was undertaken by Professor Irving[4] in 1881, and was ably accomplished by him in the course of two years. All publications referring to the lithology of the Keweenawan and Huronian formations on both sides of the lake were carefully reviewed, most of the specimens described in them were examined, and the results of this study and examination, together with a great deal of new information gathered

[1] A. WICHMAN: Microscopical Observations of the Iron-bearing (Huronian) Rocks from the Region South of Lake Superior. Ib. p. 600.

[2] CHARLES E. WRIGHT: Geol. of Wisconsin, II., 1878, p. 637.

[3] M. E. WADSWORTH: Notes on the Geology of the Iron and Copper Districts of Lake Superior. Bull. Mus. Comp. Zoölogy, 1881, Vol. VII., p. 36–49.

[4] R. D. IRVING: The Copper-bearing Rocks of Lake Superior. Monograph V., U. S. Geol. Survey, Washington, 1883.

during a trip among the dykes and sheets of the north shore of the lake, were incorporated in a monograph and published under the auspices of the U. S. Geological Survey in 1883.

The greater portion of the volume is concerned with the discussion of the Keweenawan rocks, but a brief synopsis of the character of the Huronian Series is given (pp. 367–409), and in this a few descriptions of Huronian basic eruptives are communicated. A brief synopsis of Irving's results will serve to give an idea of the relations of the different basic rocks to each other, and at the same time will serve as a basis for the present paper.

The original basic rocks of the Keweenawan, according to Irving, embrace gabbros and diabases, an anorthite rock consisting almost exclusively of anorthite, malaphyres and amygdaloids. The rocks described under the various names possess in general the characteristics of the respective types as defined by Rosenbusch in the first edition of his Massige Gesteine. The gabbros are coarse-grained rocks with a dark-gray or black color in the least coarse-grained varieties, and a light-gray color when the plagioclastic ingredient becomes greatly predominant as is apt to be the case in the coarser kinds. Their texture is highly crystalline, and their specific gravity varies between 2.8 and 3.1. The fine-grained basic rocks, whose ordinary type is diabase, make up relatively thin flows, that are almost invariably furnished with vesicular or amygdaloidal upper portions. Externally the diabases are dark in shade, being black, purple, dark green or brown, according as the rock has undergone more or less alteration. In texture they vary from medium fine-grained to cryptocrystalline. The coarser kinds grade into coarse-grained gabbros, but this gradation has never been observed in any one bed. Moreover, the diabases have undergone a great deal more alteration than the coarser gabbros, and are very strongly marked by their external characteristics, both in their fresh and altered states. They therefore seem to Irving to deserve a special name; since they possess the structure of diabases he calls them by this designation. The olivine-free diabases of the ordinary type pass into still finer grained kinds of a black or brown color. Some of these are

entirely aphanitic, and all kinds tend to a porphyritic development, carrying as phenocrysts oligoclase and more rarely labradorite and augite. Like the diabases mentioned above, the diabase-porphyrites are furnished with amygdaloidal upper portions. In the few instances in which the olivine-bearing rocks have an undifferentiated glassy base, they are called melaphyres, although placed among the fine-grained diabases.

The most of the basic rocks of the region are in the form of interbedded sheets. Dykes are rare. When they occur, their material appears to be diabase or diabase-porphyrite. It is rarely coarse enough to be classed with the rocks called gabbro.

In the Huronian areas on the other hand, large dykes of coarse-grained gabbros[1] cut through the sedimentary beds, and with these are intercalated thick beds of gabbro, and occasionally a few thinner ones of diabase.

Since Irving's general classification of the rocks in question a few other publications have appeared in which the petrography of small areas, and the descriptions of hand-specimens are treated.

Messrs. Herrick, Tight and Jones[2] busied themselves during one summer with a study of the rocks around Michipicoten Bay, an arm of Lake Superior extending northeasterly into Canada. Their paper contains but little with respect to the basic eruptives not found in Irving's monograph. Dr. Wadsworth[3] has examined some of the specimens gathered by the Minnesota Survey and has divided the basic rocks into peridotites, basalts, including gabbros, diabases, melaphyres, diorites and norites, peridotites, and rocks regarded as altered andesites. All of Dr. Wadsworth's descriptions are marked by exactness, but the conclusions based upon them are rendered less valuable than they would have been had Wadsworth himself not been compelled to depend upon others

[1] It will be shown later that most of the rocks called gabbro by Irving and others, are not gabbros, but are coarse-grained diabases.

[2] C. L. HERRICK, W. G. TIGHT and H. JONES: Geology and Lithology of Michipicoten Bay. Bull. Scient. Lab. of Denison Univ., Vol. II., Part 2, 1887, p. 120.

[3] Dr. M. E. WADSWORTH: Preliminary Description of the Peridotytes, Gabbros, Diabases and Andesytes of Minnesota. Bull. No. 2, Geol. and Nat. Hist. Survey of Minn., 1887.

for a knowledge of the field relations of the specimens studied. Messrs. Herrick, Clarke and Deming[1] have also studied a few specimens of the gabbro, both ordinary and orthoclastic varieties, from Duluth, but they have added little to what was already known concerning them, except the suggestion of the possible dependence of the orthoclase-bearing varieties upon their environment for the peculiar characteristics which they possess.

The Canadian geologists have likewise been engaged in a study of the rocks on the north side of Lake Superior. Many allusions have been made to the massive sheets and dykes in the Thunder Bay region, but no microscopical descriptions of them have been published, with the exception of a few notes by the present writer appended to a report by Mr. Ingall[2] on Mines and Mining in the Thunder Bay Silver District. In this report the relations of the large dykes and thick beds of diabase or gabbro to the fragmental rocks of the Animikie series north of the lake are carefully sketched, and the microscopic features of the most important rocks are described. In the Appendix,[3] a few altered gabbros and diabases from both sheets and dykes are very briefly characterized. The former of these have the general peculiarities of the gabbro from the great dyke on Pigeon Point, Minnesota, referred to by the writer[4] in an article on certain contact phenomena at this place, and described at greater length[5] in a bulletin of the U. S. Geological Survey. In the first of these two papers, in addition to the reference to the Pigeon Point dyke, a few remarks are made concerning the relations of Irving's orthoclase-gabbros to the more common varie-

[1] C. L. HERRICK, E. S. CLARKE and J. L. DEMING: Some American Norytes and Gabbros. Am. Geol., June, 1888, p. 339.

[2] E. D. INGALL: Report on Mines and Mining on Lake Superior. Geol. and Nat. Hist. Survey of Canada. Montreal, 1888.

[3] W. S. BAYLEY: Notes of Microscopical Examination of Rocks from the Thunder Bay Silver District.

[4] W. S. BAYLEY: A Quartz-Keratophyre from Pigeon Point and Irving's Augite-Syenites. Am. Jour. Sci. XXXVII., 1889, p. 54.

[5] W. S. BAYLEY: The Igneous and other Rocks on Pigeon Point, Minnesota, and their Contact Phenomena. Bull. No. 109, U. S. Geol. Survey, 1893.

ties of the gabbro of the region, but no detailed descriptions of these rocks, nor of the ordinary gabbros, whose modified forms they are supposed to be, are given. Finally, Dr. A. C. Lawson[1] has mentioned some of the characteristics of certain diabases from dykes in the Archæan rocks of the Rainy Lake region, in which the gabbroitic as well as the diabasic structures are well exhibited, the former toward the centers and the latter near the sides of the masses.

The most comprehensive treatment of the "greenstones" and "greenstone schists" of the Lake Superior region is that by Dr. G. H. Williams[2] in his bulletin on the origin of the green schist, supposed to underlie the Huronian in Michigan. In this volume the author not only describes the petrographical features of the schists with which he deals, but he likewise describes in some detail the microscopical characteristics of the diabases, diabase porphyrites, diorites, diorite porphyrites and gabbros, associated with the schists, and from some of which the latter have been derived.

Within the past three years a number of papers have appeared in which reference is made to some of the special features of a few of the coarse basic rocks, both north and south of the lake, but no articles have been published that deal with their general features. Fairbanks[3] has communicated a few notes on the diorites and gabbros in the province east of the north side of Lake Superior. Irving and Van Hise[4] have given a brief synopsis of the characteristics of the diabase dykes and interbedded sheets in the Penokee iron series on the south side

[1] A. C. LAWSON: Notes on Some Diabase Dykes of the Rainy Lake Region. Proc. Can. Inst. for 1887, and Report on the Geology of the Rainy Lake Region. Pt. F., Ann. Rep. Geol. and Nat. Hist. Survey of Can. for 1887-88, pp. 57-73 and 147-164.

[2] G. H. WILLIAMS: The Greenstone Schist Areas of the Menominee and Marquette Region of Michigan. Bull. No. 62. U. S. Geol. Survey, 1890.

[3] H. W. FAIRBANKS: Notes on the Character of the Eruptive Rocks of the Lake Huron Region. Amer Geologist, I. 1890, p. 162.

[4] R. D. IRVING and C. R. VAN HISE: The Penokee Iron-bearing Series of Northern Wisconsin and Michigan. Monograph XIX., U. S. Geol. Survey, 1893. Chap. VII., The Eruptives.

of the lake, and of the gabbro, diabases, diorites, melaphyres and porphyrites of the Keweenawan overlying the Penokee series to the north, while Hall[1] has described a few hand specimens of diabases and gabbros from the Archæan of Central Wisconsin.

Further, in a discussion as to the nature of the diabase sheets interbedded with the Animikie slates and quartzites in Minnesota and Canada, which leads to the conclusion that the former are subsequent intrusions between the clastic beds, Lawson[2] gives a short generalized description of the petrographical characteristics of these rocks, and in a second article[3] he treats of the structure and composition of the anorthite rock of Irving, to which he gives the name anorthosyte. Finally, the writer in two articles refers to the coarse gabbro[4] of north-eastern Minnesota and to the peridotites and pyroxenites[5] associated with it along its northern border.

W. S. BAYLEY.

[1] C. W. HALL: Notes of a Geological Excursion into Central Wisconsin. Bull. Minn. Acad. Nat. Sciences, III., No. 2., p. 251.

[2] A. C. LAWSON: The Laccolitic Sills of the Northwest Coast of Lake Superior. Bull. No. 8, Geol. and Nat. Hist. Survey of Minnesota, p. 30.

[3] A. C. LAWSON: The Anorthosytes of the Minnesota Coast of Lake Superior Ib., p. 2.

[4] W. S. BAYLEY: A Fibrous Intergrowth of Augite and Plagioclase, resembling a Reaction-rim, in a Minnesota Gabbro. Amer. Jour. Science, XLIII. 1892, p. 515.

[5] W. S. BAYLEY: Notes on the Petrography and Geology of the Akeley Lake Region, in North-eastern Minnesota, 1892, p. 193.

A STUDY IN CONSANGUINITY OF ERUPTIVE ROCKS.

WITHOUT being distinctly formulated, the principle of consanguinity recently enunciated by Prof. Iddings has, as a working hypothesis, been the guide of studies made within the last few years on a group of Brazilian eruptive rocks, and the means of arriving at some interesting and, in part, novel results. The method of study followed, partly by plan, partly from force of circumstances, being the comparative study of a group of localities on the assumption of genetic relations between them, rather than detailed work at single points, was similar to what would be applied to the study of a sedimentary group. This method has in this case proved of great advantage, and, as a contribution to the subject of consanguinity, seems worthy of being put on record.

In 1883, the writer, whose previous training had been almost exclusively in the domains of palæontology and the distinctly sedimentary formations, finding himself in a region of crystalline and metamorphic rocks felt the need of acquainting himself with modern petrographic methods. Working in complete isolation without previous instruction in this branch, without material for comparison and almost without literature, he was also without the traditions of the science and preconceived ideas of the relations of the different petrographic groups, and thus free to follow out the lines of investigation suggested by their apparent field relations.

In working over the material at hand in the National Museum at Rio, attention was attracted to specimens of nepheline-syenite, or foyaite (using that term as a general title for the holocrystalline nepheline-orthoclase rocks) and as one of the localities, the peak of Tingua, was readily accessible from Rio an attempt to determine its field relations was resolved upon. This heavily wooded mountain proved a hard nut to crack, and several excursions gave very slender results beyond the fact that

with the predominant foyaite, phonolite and basaltic rocks, which have since been named monchiquites by Prof. Rosenbusch, occurred. These two last types, found only in loose blocks or in small dykes in gneiss that was clearly older than the foyaite, gave no idea of their relations to the latter rock except that at one point a small dyke of phonolite containing polyhedral inclusions of foyaite, like raisins in a pudding, was observed cutting foyaite of the same type as the inclusions. An examination of a series of railroad cuttings between the peak and the city showed a plexus of phonolite and monchiquite dykes together with a peculiar feldspathic rock of syenitic aspect, which, as they did not extend to the city, were suggestive of a possible genetic connection with the eruptive center of Tingua, or of some other similar center in the vicinity.

The occurrence of phonolites, hitherto only known on Brazilian soil on the volcanic island of Fernando de Noronha, suggested a search for phonolitic centers of eruption. About this time a chance collection made by a naval officer from the island of Cabo Frio, 60 miles from Rio, came to hand. As it contained specimens of both phonolite and foyaite, an excursion was resolved upon, guided by the thought that a rocky island on an open coast should give good exposures and thus perhaps prove a better point than Tingua for the study of the problems presented in this mountain. The island, from two to three miles long and from one-fourth to one-half mile wide, was found to give an almost continuous rock exposure about its entire margin. About four-fifths of the island is composed of coarse grained sodalite-bearing foyaite somewhat different from the Tingua type, and like it cut by numerous dykes of phonolite. The remainder consists of augite-syenite of two types, except a small point which is distinctly tuffaceous and cut by innumerable small dykes of a basaltic character. In one place dyke-like masses and large boulder-like inclusions of a pyroxene-plagioclase rock of a gabbro type occur. The coast of the mainland, distant half a mile more or less from the island, is entirely free from rocks of a syenitic character, and is composed of gneiss cut

by numerous dykes of phonolite, monchiquite and augite-syenite porphyry, as well as of diabase which, as it occurs everywhere in the gneiss regions of Brazil, was not taken into account. Although nothing definite on the field relations of these various rocks could be made out, the idea suggested at Tingua of a possible genetic relation between foyaite, phonolite and monchiquite was strengthened by this repetition of the association and mode of occurrence, that is to say, of a central mass of foyaite with apophyses of phonolite and monchiquite. Aside from this, the association of foyaite with augite-syenite, with a plagioclase rock and with tuff of a volcanic character, suggested other lines of investigation not in accord with the usually received notions regarding these rocks.

Before a second projected excursion to Cabo Frio could be realized a chance specimen of foyaite from the Poços de Caldas in southern Minas appeared at the Rio Museum. As a railroad was under construction in this region the idea at once presented itself that, aside from a study of this district, possibly Tingua and Cabo Frio might be studied more advantageously several hundred miles away than at those points themselves. Instead, therefore, of returning to Cabo Frio an excursion was made to Poços de Caldas where the expectations formed were more than realized. About twelve kilometers of almost continuous rock cutting up a steep mountain slope giving one of the finest and most varied exposures of eruptive rocks in the world, was found. Here immense masses of tuff are seen to be cut by both foyaite and phonolite ; dykes and sheets of foyaite pass into phonolite at their margins ; small masses of phonolite[1] are seen included in foyaite and *vice versa* masses of foyaite are included in phonolite. Considerable masses of a leucite rock, the first known from South America, cut by and buried under phonolite and presenting tuffaceous facies also occur. Small stringers of augite-syenite were noted in the tuffs and phonolite, and nests of

[1] The name phonolite is retained for these rocks since no petrographer, not knowing their association, would ever think of calling them anything else, although some, with that knowledge, prefer to call them nepheline-syenite porphyries or tinguaites.

decomposed crystals, at first taken for analcime, as well as polyhedral inclusions similar to those of the phonolite of Tingua were obtained. To complete the felicity of the excursion a cutting at the foot of the mountain showed the eruptive rocks to be in part, at least, contemporaneous with Carboniferous strata.

With the data here obtained a paper was prepared and presented to the Geological Society of London (Quart. Jour. 43, 1887) announcing the discovery and general distribution of nepheline and leucite rocks in Brazil, and the general conclusion that the Poços de Caldas eruptive center is volcanic in the most restricted sense of the term, that it is of Carboniferous age, and that here foyaite and phonolite occur as different phases of the same magma.[1]

The attack on Tingua was now renewed with the expectation that a diligent search would reveal something analogous to the Caldas region. A trip to the top of the peak showed little of interest beyond a dyke of phonolite cutting foyaite at the very summit. An examination of the margins, well shown by the cuttings of an extensive series of railroad and pipe lines (for the water supply of Rio) at the front, a river valley at the back and roads over the ridge at both ends of the peak, showed that the foyaite is limited to the massif and nowhere presents unequivocally the character of dykes. Two cuttings, one a tunnel, through a spur covered with foyaite boulders as if from the outcropping of a dyke, is conclusive on this point, as only gneiss was found *in situ*. The eruptive rocks are therefore placed like a plaster on the top and slopes of a gneiss ridge in a manner exceedingly suggestive of volcanic conditions. By forcing a way through the dense forest into the crater-like valley of a stream coming from the very heart of the mountain, the long-sought-for evidence of fragmental eruptives and of extensive masses of phonolite in

[1] Subsequent explorations of the Caldas center proves it to be one of the grandest volcanic masses of nepheline rocks known, measuring from fifteen to twenty miles in diameter. Contrary to the first impression the foyaite masses are comparatively insignificant, and the massif is composed essentially of phonolite and tuff with possibly a large proportion of basic leucite rock. A large and important mass of augite-syenite appears to form part of the same volcanic massif.

sheets rather than dykes was found. A complete analogy, as regards the essentially volcanic character of the massif, with the Caldas region was thus established with the addition of evidence of a lava-flow-like character in the foyaite masses. (Quart. Jour. XLVII., 1891).

A chance fracture of a Caldas specimen showing obscurely an appearance of dodecahedral faces on the external surface of the singular polyhedral inclusions so characteristic of the two places, suggested the search for partially decomposed material which by cleaving around the inclusions would show their true form and reveal the mystery of their origin. This search was rewarded with the discovery of free masses of foyaite, like those of Magnet Cove, Ark., having the external form of leucite. The presence of such rock masses with crystalline outlines in both phonolite and foyaite is another link in the chain of evidence of consanguinity of foyaite, phonolite and leucite rocks, while the presence of accessory plagioclase in some of these masses, taken in connection with the occurrence already noted at Cabro Frio, suggests another interesting line of investigation.

Meanwhile another series of studies presented in an unexpected manner certain new and interesting phases of the problem. Work had been commenced on a deposit of magnetic iron ore at Ipanema in the state of São Paulo where, from the extreme decomposition of the rocks and other unfavorable circumstances, but little could at first be made out beyond the association of the ore with a peculiar clay made up in large part of scales of hydrous mica. An ore of similar character at Jacupiranga in the same state was being investigated by Mr. Henry Bauer, a German mining engineer, and the collections sent by him showed the presence at that place of an undescribed type of holocrystalline nepheline-pyroxene rock since denominated jacupirangite,[1] which, by enrichment in iron, passes to an iron ore, and, by secondary alteration of the pyroxene, affords the same peculiar micaceous clay. Certain basic

[1] Am. Jour. of Science, XLI., 1891, p. 311. The same, or a very similar, type was described simultaneously from Finland by Ramsay and Berghell with the name of ijolith (Geologiska Föreningens i Stockholm Förhandlingar, No. 137, 1891).

eruptives in these collections suggested a comparison with the Tingua and Cabo Frio monchiquites, and Mr. Bauer was requested to search for the characteristic rocks of these places, specimens being sent him for comparison. The return mail brought typical specimens of foyaite, and with this indication of a new locality for that rock, and in the hope of being able to study the Ipanema ore deposit more advantageously at another place, an excursion to Jacupiranga was resolved upon. Under the guidance of Mr. Bauer, and aided by subsequent investigations by him and Dr. Eugen Hussak, the district was found to consist essentially of jacupirangite cut by dykes of foyaite with which is associated phonolite, various types of augite-syenite and a micaceous pyroxene-plagioclase rock in such a way that there is no escaping the conclusion of a genetic relation between these various types. Outlying dykes of the plagioclase rock assume in one place the characters of a gabbro, in another, those of a teschenite. Among the outlying dykes of the district are various types of basic eruptives, including leucite-basanite, vosgesite and syenite-porphyry whose relations to the eruptive center are less clear, but which are also suspected to be genetically connected with the nepheline-bearing types. Most interesting is a cryptocrystalline orthoclase-pyroxene rock passing to coarse grained augite-syenite and presenting a tuffaceous facies clearly indicative of volcanic action.

With the clues obtained at Jacupiranga the study of Ipanema became comparatively easy. The jacupirangite type passing to an iron ore was found as a dyke with the facies of a breccia at the margin, traversing decomposed rock which is evidently identical with the compact augite-syenite of Jacupiranga. By diligent search the latter was found in a sound condition and presenting a variety of interesting phases, such as a passage to coarse grained augite-syenite, tuffs identical with those of Jacupiranga and, most interesting of all, a basic facies in which the orthoclase is replaced by phosphate of lime in the form of apatite. A singular mode of occurrence, and one bearing directly on the question of consanguinity, is that of micro and macroscopic inclusions,

or segregations, of both the feldspathic and phosphatic types of augite-syenite in a phonolitic nephelinite, apparently without feldspar. The bulk of the iron ore at this place occurs as rounded nodular segregations associated with apatite in a decomposed rock which was evidently coarse grained and micaceous. This was evidently not jacupirangite, but apparently some peculiar type of nepheline or augite-syenite. Except for the absence of black garnets it apparently corresponds closely with the ore-bearing rock of Magnet Cove, Ark., described by the late Dr. J. F. Williams. It may be noted in this connection that the same character (absence of black garnet) distinguishes the jacupirangite from the ijolith of Ramsay and Berghell.

As in the Caldas region, there is at Ipanema evidence that the eruptive action took place in the late Carboniferous or post-Carboniferous times. This coincidence of age at two of the localities may perhaps justify the assumption (which cannot be directly proven for lack at the other places of sedimentaries intermediate between the very ancient and the very modern), that all of these eruptive centers are substantially contemporaneous. Bearing on this question of age, as also on that of consanguinity, is the fact that in a region characterized by Devonian and probably also Carboniferous strata in Paraguay, Pohlmann has reported nepheline-bearing basalt, and Dr. J. W. Evans has lately communicated specimens of foyaite and augite-syenite from Pão de Assucar on the Paraguay, proving that this mass, hitherto reputed to be granitic, represents another eruptive center similar to those studied in eastern Brazil.

The evidence of consanguinity of foyaite and phonolite consists of an intimate association within limited areas at all of the localities mentioned, except Ipanema, where neither type has as yet been found in a condition to be positively identified; of a direct passage to phonolite at the margins of foyaite masses at Caldas; of inclusions of phonolite in foyaite at the same place and conversely of inclusions, evidently formed *in situ* of foyaite in phonolite at Caldas and Tingua. In this connection may be mentioned an inclusion of the type of

foyaité, described by Prof. Rosenbusch and Dr. G. H. Williams from the phonolite massif of the island of Fernando de Noronha, whose eruption is presumed to be of much later date than that of the continental centers above described. Whatever may be the explanation of the assumption of the leucite form, without the substance of that mineral, by these inclusions at Caldas and Tingua, this phenomenon may also be cited as an evidence of consanguinity. Confirmatory evidence is afforded by the intimate association of typical leucite and nepheline rocks in the Caldas massif, and perhaps also by the occurrence in Paraguay.

The evidence of consanguinity of the augite-syenite type with those bearing nepheline is almost equally complete. At Tingua, where there is an apparent lack of this type, a single large fragment was found as an inclusion in foyaite. At Jacupiranga, a direct passage by disappearance of nepheline, from foyaite to one phase of augite-syenite could be traced, while other phases of the same type were found associated with foyaite in the same dyke or boss. Most interesting is the association of this type at Jacupiranga and Ipanema with nepheline rocks more basic than the foyaites and phonolites, such as the jacupirangites and phonolitic nephelinites, in the latter of which it occurs as an inclusion or segregation. In this connection it is interesting to note the tendency, rare among the orthoclase rocks, of this type to present olivine as an accessory element.

Still more interesting, though less conclusive, are the indications of consanguinity of foyaite with a group of plagioclase rocks hardly, if at all, distinguishable from those of entirely different genetic relations. At Cabo Frio the appearance is certainly that of segregations of a plagioclase rock in the midst of foyaite, though farther investigation is desirable. At Jacupiranga the two types not only occur in the same dyke or boss, but nepheline has actually been observed as a rare accessory in the gabbro-like rock. The appearance of plagioclase in the pseudo-leucite crystals of Tingua bears on the same question, as does also the appearance in a large collection of phonolite from Fernando de Noronha of a single specimen of an andesite-like rock, which unfortunately

was not observed in time to be included in the material sent to Dr. G. H. Williams for study. Apparently there is a group of gabbro and diabase-like rocks whose genetic relations are with the nepheline-bearing rocks rather than with the ordinary members of the groups which they so closely resemble.

The peculiar and varied group of basic dyke rocks recently denominated monchiquites by Prof. Rosenbusch, afford evidences of consanguinity by their almost constant association, as apophyses, with the nepheline-bearing eruptive centers to whose immediate vicinity they appear to be limited. If certain decomposed dykes at Caldas and Ipanema are correctly referred, this group occurs at all the Brazilian localities. A single instance of a basic segregration resembling this type has been observed in a dyke of phonolite. The occurrence within the space of a few meters in the Tingua phonolitic tuffs of three small dykes of this type, of which two, standing alone, would be taken as representing tephrite and limburgite is suggestive of another line of consanguinity. Equally suggestive is the occurrence of vosgesite in the vicinity of the Jacupiranga center of eruption.

Finally the evidence of volcanic action in the presence of fragmental eruptives found at all of the five localities in constant association with types ordinarily regarded as plutonic, such as augite-syenite, is exceedingly suggestive.

ORVILLE A. DERBY.

SÃO PAULO, BRAZIL, Aug. 1, 1893.

THE DISSECTED VOLCANO OF CRANDALL BASIN, WYOMING.*

THE writer in exploring the north-eastern corner of the Yellowstone National Park and the country east of it came upon evidences of a great volcano, which had been eroded in such a manner as to expose the geological structure of its basal portion.

The work was carried on as a part of the survey of this region, under the charge of Mr. Arnold Hague of the U. S. Geological Survey. The paper is an extract from a chapter in the final report on the Yellowstone National Park in process of completion, and the writer is indebted to Major J. W. Powell, Director of the Survey, and to Mr. Hague, chief of the division, for permission to present it at this time in anticipation of the publication of the final report.

The area of volcanic rocks described is but a small portion of the great belt of igneous material that forms the mountains of the Absaroka range, lying along the eastern margin of the Yellowstone Park.

The volcano of Crandall Basin is one of a chain of volcanic centers situated along the northern and eastern border of the Yellowstone Park, which are all distinguished by a greater or less development of radiating dikes, and by a crystalline core eroded to a variable extent.

The Palæozoic and Mesozoic strata, which formed an almost continuous series to the coal-bearing Laramie, had been greatly disturbed and almost completely eroded in places before the volcanic ejectamenta in this vicinity were thrown upon them. The period of their eruption is, therefore, post-Laramie, presumably early Tertiary.

The first eruptions of andesite were followed by those of basalt in great amounts, and these by others of andesite and

*Abstract of a paper read before the British Association for the Advancement of Science, September, 1893.

basalt like the first. This was succeeded by a period of extensive erosion; reducing the country to nearly its present form. Then came the eruption of a vast flood of rhyolite constituting the Park plateau, which was followed in this region by smaller outbreaks of basalt. The last phase of volcanic activity is found in the geysers and fumaroles which have rendered this region famous.

The volcano of Crandall Basin consists chiefly of the first series of basic andesites and basalts. The earlier acidic andesite, which occurs beneath these rocks, appears to be the remnants of eruptions from neighboring centers.

Nothing remains of the original outline of the volcano. The district is now covered by systems of valleys and ridges of mountain peaks that rise from two thousand to five thousand feet above the valley bottoms. The geological structure of the country, however, makes its original character evident.

The outlying portions of the district to the south, west, and north consist of nearly horizontally bedded tuffs, and subaërial breccias of basic andesite and basalt. With these are intercalated some massive lava flows, which are scarce in the lower parts of the breccia, but predominate in the highest parts, above an altitude of ten thousand feet. Here they constitute the summits of the highest peaks.

In contrast to the well-bedded breccias around the margin of the district, the central portion consists of chaotic and orderless accumulations of scoriaceous breccia with some massive flows. These breccias carry larger fragments of rocks and exhibit greater uniformity in petrographical character.

A still more noticeable feature of the central portion of the district is the occurrence of dikes which form prominent walls, and may be traced for long distances across the country. The greater part of them are found to converge toward a center in the highest ridge in the middle of the drainage basin of Crandall creek. A small number converge toward a second center three or four miles east of the first. In the southern part of the district there are many dikes trending toward a center near the

head of Sunlight Basin, about fifteen miles south of the Crandall center.

The center toward which the Crandall dikes converge is a large body of granular gabbro, grading into diorite. It is about a mile wide, and consists of numerous intrusions penetrating one another and extending out into the surrounding breccia, which is highly indurated and metamorphosed in the immediate vicinity of the core. Within the area of indurated breccia the dike rocks become coarse grained rapidly as they approach the gabbro core. This was undoubtedly the central conduit of an ancient volcano, the upper portion of which has been eroded away.

Upon comparing the geological structure of this region with that of an active volcano, like Etna, it is apparent that the lava flows which form the summits of the outlying peaks must have been derived from lateral cones fed by dikes radiating from the central conduit. And assuming that the volcano of Crandall Basin was similar in type to that of Etna, an idea of its original proportions is derived by constructing upon profile sections through the Crandall cone the outline of Etna. If the erosion of the summits of the highest peaks is neglected, the resulting height of the ancient volcano above the limestone floor is estimated at about thirteen thousand four hundred feet. This is undoubtedly too low, and is well within the limits of present active volcanoes. Erosion has removed at least ten thousand feet from the summit of the mountain to the top of the high central ridge in which the granular core is situated, and has cut four thousand feet deeper into the valleys on either side. It has prepared for study a dissected volcano, which, it is hoped, will in time reveal some of the obscurer relationships existing between various phases of igneous rocks.

Petrological Features.—It will not be possible in an abstract to do more than present, in the briefest manner, the more salient features of the petrology of the rocks of this volcano. The rocks are mostly the same as those in various parts of the Yellowstone National Park, some of which have been described in another place. The older acidic breccia consists of fragments

and dust of hornblende-mica-andesite, hornblende-andesite, and hornblende-pyroxene-andesite. They are partly glassy and partly holocrystalline. In some places they appear to pass into the overlying breccia, but in others they have been eroded and weathered before the latter were thrown over them.

The upper breccia, which constitutes the main mass of the volcano, is basaltic as a whole. It consists of pyroxene-andesite and basalt, the latter predominating in the upper part of the accumulation. The massive flows, as far as investigated, are all basalt. The composition varies constantly within narrow limits. A greater part of these rocks contain glassy groundmass.

The rocks constituting the dikes exhibit more variation than the breccias, though the majority of them are like the breccias in composition and habit, being basalt. They are generally more crystalline. A great many dike rocks resemble the basalts in outward appearance, but have little or no olivine, and are more crystalline. The absence of olivine from the more crystalline forms of these rocks appears to be due to the conditions which influenced the crystallization of the rocks and not to their chemical composition. For in some cases what appear in hand specimens to be decomposed olivines are found to be paramorphs after this mineral, consisting of grains of augite, magnetite, and biotite. As the rocks become more crystalline biotite becomes an essential constituent; the porphyritical minerals lose their sharpness of outline and assume some of the microscopical characteristics which they possess in gabbro.

Within the core the coarest grained forms are gabbro. The composition varies in different parts of one continuous rock mass, and also between different intrusions within the core. The transition is from gabbro to diorite with biotite and quartz; and the extreme variety is that form of granite called aplite; the range in silica being from 51.81 to 71.62 per cent.

Fine grained, andesitic equivalents of diorite occur in dikes outside of the core, but none of the most silicious varieties have been found outside of it. From this it appears that toward the end of volcanic activity near the core the composition of the

magmas became more and more silicious, and the volume of the lava erupted smaller. But this change in composition was not uninterrupted, for there are evidences of the alternate eruption of basic magmas as well. Dikes of more silicious rocks are traversed by later dikes of basic rocks. This has taken place both within and outside of the core. Some of these basic rocks are uncommonly low in silica for rocks of this region. They are all found at some distance from the core, with one exception, which is an intrusion within the core. They are lamprophyric in the sense used by Professor Rosenbusch, and approach more or less closely typical camptonites, monchiquites, kersantites, and minettes. They are connected with the basalts of the district by mineralogical and structural transitions.

These exceptionally basic rocks are the chemical complements of the acidic ones in the core and appear to be among the latest extrusions. While they agree with one another in having a low percentage of silica, they differ in the relative abundance of magnesia, lime and iron oxide on the one hand, and of alumina, soda and potash on the other.

As already pointed out by the writer in another place, the variability in composition of all of the volcanic rocks in this volcano illustrates one mode of differentiation of a magma at a particular center of eruption. A comparison of the chemical and mineral composition of the rocks of this district furnishes additinal evidence of the fact that magmas which are chemically similar will crystallize into different groups of minerals according to the conditions through which they pass. Thus chemically similar magmas may form basalt under one set of conditions, and gabbro under others; the first composed of plagioclase, augite, olivine, magnetite and sometimes hypersthene; the second consisting of plagioclase, augite, hypersthene and biotite, besides some magnetite, orthoclase and quartz, with or without hornblende.

Minerals, then, which are primarily functions of the chemical composition of rocks are also functions of the physical conditions affecting crystallization. Some of the conditions under which the molten magmas solidified within the dikes and core of the

volcano of Crandall basin, may be inferred from a consideration of the geological structure of this ancient volcano. The magmas which solidified within that portion of the core now exposed, and those in dikes within a radius of two miles, must have occupied positions at nearly the same distance beneath the surface of the volcano, that is, at a depth of about 10,000 feet and over. The one was as deep-seated or abysmal as the other, and yet their degrees of crystallization range from glassy to coarsely granular.

The influence of pressure on the crystallization is not recognizable either in the size of grain or the phase of crystallization. Marked changes in the crystallization may be traced horizontally in the immediate vicinity of the core. They are rapid near the core, and are accompanied by the induration and metamorphism of the surrounding rocks. They are in a general measure independent of the size of the rock-body, since narrow dikes within the core are coasely crystalline, while much broader ones in the surrounding breccias are very fine grained. It was, unquestionably, the differences in the temperature of the core rocks and of the outlying breccias which affected the degree of crystallization. The former must have been more highly heated than the latter rocks, and the magmas solidifying within them cooled much slower than those injected into the outlying parts of the volcano. In this case the depth at which the magmas solidified appears to have been of little moment in comparison with the temperature of the rocks by which they were surrounded.

The core of gabbro and diorite with an intricate system of veins of middle grained porphyritic rocks, and radiating dikes of aphanitic and glassy lavas, encased in an accumulation of tuffs and breccias with flows of massive lava, constitute an extinct or completed volcano. The central core consists of the magmas that closed the conduit through which many of the eruptions had reached the surface. In solidifying they became coarse grained. The question naturally suggests itself, Are these coarse grained rocks any less volcanic than those that reached the surface? What part of a volcano is non-volcanic?

JOSEPH P. IDDINGS.

NOTES ON THE LEAD AND ZINC DEPOSITS OF THE MISSISSIPPI VALLEY AND THE ORIGIN OF THE ORES.

THE recent closing down of the silver mines of Colorado and other Western states means not only a lessening of the silver production of the country, but also the shutting off of its greatest source of lead supply. During the past few years over two-thirds of the total yield of domestic lead has been from the argentiferous lead ores of Colorado, Utah, Idaho, Montana and Nevada. Unless operations are resumed in the West, the demand must consequently soon be concentrated upon the deposits of non-argentiferous lead in the Mississippi Valley, which have been in the past the sole important producers. A rise in the price of lead is to be expected as a result, which, in turn, will lead to increase in exploitation and development.

The question naturally arises, therefore, to what extent are these Mississippi Valley deposits to be depended upon for future supply. They have been large and almost constant producers in the past; will they continue to be such in the future? The history of their development, which is in many respects remarkable, lends color to the hope that such will be the case, especially in Missouri. Lead mining was begun in that state as much as 170 years ago, and has continued almost uninterruptedly since. Indeed, the first deposit worked, that of Mine La Motte, has up to this year supplied large quantities of ore, the total value of its product to date being in the neighborhood of $8,000,000. The various bodies of ore have shown signs of exhaustion from time to time, and the industry in the state has waned. About the year 1854 the condition was such that even so competent a judge as Prof. J. D. Whitney[1] ventured the prediction that the supply was nearly exhausted, and that the lead mining of Missouri was a thing of the past. But ever after such depression, deeper excavations have developed new bodies of untouched ores, wider explo-

[1] Metallic wealth of the United States, p. 419.

rations have revealed new fields, or improvements in mining and metallurgical methods have made previously rejected ores available. Along with this, the utilization of the associated zinc ores has led to the opening up of deposits which previously lay untouched, enclosing often unexpected quantities of lead. During the past twenty years Missouri's production has reached large proportions. The total amount mined during this period is fully twice that of the preceding 150 years—a startling refutation of the early adverse predictions. The output during recent years has been only second to Colorado's, and this year will probably be first among the states of the Union; the total amount produced to date probably equals, if it does not exceed, that of any other state.

Similar in some respects are the facts of zinc production. The mining of these ores does not, however, date much more than twenty years back, and hence the industry has not suffered much from the vicissitudes of the early mining. The production grew rapidly from its beginning, and now ranks first in the country. The total output up to the present time is nearly equal to the combined total productions to date of all other states in the Union.

The showing for the Upper Mississippi or Wisconsin zinc and lead area is not quite so good. Mining there dates hardly more than 100 years back, and it was not on an active basis before 1823. The period of maximum work was about the year 1845, and soon after this time Prof. Whitney seems to have been of the opinion that its prospects were better than Missouri's, though he predicted a continued decline. The utilization of the zinc ores began about 1860, which tended to sustain the mining industry and the production of lead, though on a much reduced scale. In the early seventies the production of zinc was quite large and something like a resuscitation of mining took place. During the past thirteen years there has, however, been a general decline, and recently little mining has been in progress. At the time of maximum activity, in 1845, the production of lead was about 27,000 tons per annum; but that of zinc ore, in 1872, was only 22,000 tons. The total amount of lead produced to date is prob-

ably something over 650,000 tons, and of zinc ore only about 250,000 tons.

With such facts in mind it is of interest to note that the deposits to which they relate are the subjects of renewed study at the present time, and the prospect of increased demands upon them, above referred to, makes the revival of the discussions of their origin and mode of deposition most timely.

At the recent meeting of the American Institute of Mining Engineers, held as part of the International Engineering Congress, three papers were presented bearing, in whole or in part, upon the ores of the Mississippi Valley, and another, on the Bertha zinc mine of Virginia, described an ore body belonging essentially to the same class. These papers were by Messrs. F. Posepny[1], W. P. Jenney[2], S. F. Emmons[3], W. P. Blake[4], and W. H. Case[5], respectively.

The first of these papers, by Professor Posepny, is a description and discussion of ore deposits in general, in which he advocates their deep-seated origin through the medium of hot solutions derived from great depths. The second paper, by Dr. Jenney, is an exposition of his views concerning the origin of the Mississippi Valley ores, derived from his recent studies in the region. He repudiates the explanation of lateral concentration advocated by Whitney and Chamberlin, and reverts to the old ideas of Owen and Percival, that the ores have come from below, thus harmonizing with Posepny. The other three papers are principally descriptive, though Mr. Emmons quotes Dr. Jenney's conclusions as applied to the Mississippi Valley ores.

Posepny's direct reference to the ores here discussed is brief. He marshals few facts from the region itself in support of his theory, but rather argues, in a negative way, that no great obstacles exist there which would prevent its accceptance. Thus,

[1] The Genesis of Ore Deposits.

[2] The Lead and Zinc Deposits of the Mississippi Valley.

[3] Geological Distribution of the Useful Metals in the United States.

[4] The Mineral Deposits of Southwest Wisconsin.

[5] The Bertha Zinc Mine.

as positive evidence in Missouri, he states that while the deposits away from the granite and porphyry "islands" of southeastern Missouri consist chiefly of lead and zinc ores, "other metals, such as copper, cobalt and nickel occur as the Archean foundation rocks are approached." This circumstance, he states, is "an indication that the source of the lead deposits also is to be sought in depth." Whatever may be the value of this "indication," the facts, as stated, do not hold generally, in the opinion of the writer. Professor Posepny reasons, presumably, from observations made at Mine La Motte, where such conditions exist. At other places, however, these changes in composition are not observed as the crystalline rocks are approached. At Bonne Terre copper pyrite was found in the old *upper* workings containing about four per cent. of nickel and cobalt. It does not characterize the deeper ores. At Doe Run, a mine recently opened, work is prosecuted along the old water-worn pre-Cambrian surface of the Archean granites, amid the very conglomerate boulders, and very little copper pyrite with cobalt and nickel is found. Again, at other localities in St. Genevieve, Franklin, Crawford and other counties, copper ores occur remote from any granite or porphyry outcrops, and well above the basal beds of the Cambrian.

In the way of negative evidence, our author, in considering the Wisconsin deposits, seems to think the absence of ores in the great thicknesses of limestones and sandstones which underlie the productive horizons a by no means conclusive fact as opposed to their deep-seated source, and suggests that the solution may have come up through a passage not yet exposed, and even that fault fissures and eruptive dikes exist which have not been discovered. From the fact that he refers in this connection only to Whitney's report of 1862, we conclude that he has not had access to the later and more exhaustive works of Strong and Chamberlin. Perhaps, with the full light conveyed by these reports and accompanying maps, Professor Posepny might have attached more importance to the objections raised. It is difficult to conceive how such a passage for the solutions as he suggests

could possibly exist without its presence having been revealed and its course traced, with all the widespread mining and exploring which has been conducted in this region during the past seventy years. Neither can one see how the solutions could traverse the intervening great thicknesses of water-soaked sandstone without becoming diffused, in great part at least. The failure to find such a passage and the absence of the ores in the beds assumed to have been traversed, though evidence of a negative character is so strong that it becomes of almost positive value in support of the theory of lateral segregation.

Dr. Jenney, in support of his position, recognizes systems of fault fissures in the ore districts of both south-western and south-eastern Missouri, which cross each other in different directions; these, he considers, served as channels for the metal bearing solutions, and the association of the fissures with the ore bodies he adduces as evidence of such derivation. The deposits of the south-western portion of the state occur almost exclusively in the Mississippian or Lower Carboniferous limestone. Cross fissures or fault fissures in the rocks, if they exist, are not very apparent. The strata are undoubtedly very much shattered in certain limited areas, and have been subjected to extensive subterranean erosion and corrosion and great silicification. Of a system of extensive or considerable faults, recent stratigraphic work in this region has, however, revealed nothing.

In the Cambrian limestones of the eastern part of the state the conditions are somewhat different. Crevices and fissures are there plainly developed, and evidence of considerable faulting is indubitable. In Franklin County such vertical crevices have supplied large quantities of ore. In that portion of the southeast to which reference is especially made, however, and which has produced by far the bulk of the lead, the crevices, whether marking faults or not, are of insignificant dimensions, and the experience has been that they contained themselves little or no ore. On the contrary, the great ore masses consist of galena disseminated through a thickness of the country rock, often of fifty feet or more. At Bonne Terre a tract 1300 feet long by 800

feet wide has been mined out of such diffused ore. The crevices which traverse this ore body are frequently almost blind, and can only be detected by the drip of roof water. These are such as occur in almost any massive rock. Further, one of the most important faults in this region, which traverses the country about two miles north of Mine La Motte, with an apparent throw of 300 feet, is entirely unaccompanied by ore, though the adjacent ground has been prospected with the diamond drill. Again, not a single instance can be recalled by the writer, in those mines which work to the very contact with the underlying granite, where faulting crevices extend down into that rock. They possibly do so extend in some instances, but there is no positive evidence adduceable that they then continue ore bearing. Apart from this, however, the association of ore and crevices, of course, does not denote by any means a deep-seated source for the ore. Such crevices generally act both as channels controlling their distribution, and as receptacles for their accumulation whatever the source of the ores. Hence, a disturbed and creviced region, which is in other respects adapted to the reception of ores, will be their most natural habitat. Therefore the explanation of the localization of the deposits based upon such conditions is equally consistent with any of the common theories of ore derivation. The same, it would seem, can be said concerning the observed paragenesis of the minerals and the growth of crystals, in which Dr. Jenney sees additional foundation for his conclusions. If we accept the broader idea of lateral secretion, which does not demand that a mineral shall be derived from the very rock to which it is attached, but recognizes abundant flow along crevices and through porous strata and a consequent free transfer of solutions from place to place, all the phenomena find at least an equally ready explanation. It is argued further, in this paper, as against the lateral secretion theory, that the metallic contents of the country rocks are insufficient to have supplied the ore bodies. The grounds for this statement are only suggested; but, to the best of our knowledge, the fact yet remains to be proven. Due allowance is not made for the many and various ways in

which minute quantities of substances disseminated through vast volumes of rock may be brought together.

In evidence of the post-Carboniferous age of the deposits the statement occurs several times in Dr. Jenney's paper, that the ores occur in the Coal Measures. This, we think, should be made with limitations. They are found in shales of that age in Jasper county, and at a few other localities, but these shales are in isolated patches, which occupy depressions in the older ore-bearing Mississippian rocks. The metallic contents of the coal may, hence, be derived, by some secondary process of transfer, from adjacent ore bodies. In any case, the Coal Measures in the state, as a whole, are practically destitute of these ores, and they can thus hardly be stated to occur in that formation, whether their absence be due to their prior formation or to limitations in their distribution determined by physical causes.

Dr. Jenney seeks further to find support for the hypothesis of the deep-seated origin of the ores through analogy, in stratigraphy and geologic history, with regions of the far West. This attempt does not seem, in our judgment, to be successful. The last pronounced regional disturbance of both the Ouachita and Ozark uplifts was immediately after the Coal Measure period. In Arkansas this was accompanied by great flexing of the strata. There is no evidence in the Ozark uplift of any intense disturbance of post-Cretaceous date, or of the presence, even at great depths, of flows of such igneous rocks as accompanied the uplift and preceded the ore formation of the Rocky Mountains. As already expressed, the Missouri ores cannot be properly considered to occur in the Coal Measures of the state. Did such a profound fissuring take place in post-Cretaceous times as Dr. Jenney's hypothesis requires, we should expect to find it extending into the body of the Coal Measures, accompanied by the ores. At least faulting or other such exhibition of disturbance would be found, which phenomena do not characterize these rocks.

Over and above these considerations affecting the quality of the support of this theory, there still remain the positive obstacles to be disposed of. The almost entire absence of the

precious metals in the Missouri ores is a fact which further weakens the force of any analogy which may exist between their conditions of deposition and those of the Rocky Mountain ores. How are the objections raised by Whitney and Chamberlin, discussed in a previous paragraph, to be met; such as the facts that faults are practically absent from the region; that there is little ore in the underlying Lower Magnesian beds and none in the Potsdam and St. Peter's sandstones; that no deep and continuous crevices like true fissures are found; that no hydrostatic cause is assigned for the ascension of the solutions from great depths. How could the ores be carried across such thick pervious and water-soaked strata as those of the Potsdam and St. Peter's formations?

The generally accepted facts that the deeper-seated rocks are richer in metallic constituents; that subterranean waters are of high temperature and under great pressure, and consequently are powerful solvents; that the relief of pressure and the diminution of temperature accompanying the ascent of such solutions supply an abundant cause for the deposition of their metallic burdens, are all good and enticing general reasons in favor of the adoption of the theory of a deep source for *all* of our metalliferous deposits. Yet, on the other hand, we must recognize that *some* of our ores, notably those of iron and manganese, cannot be assigned such an origin. Why is it not possible, on general grounds, that other ores should be gathered as are those of these two metals? In reply, it is manifest that we cannot rely entirely upon such general principles, as they are at present understood; but must resort to specific facts in connection with special cases. Few definite facts relating to this Mississippian area have been adduced in these recent papers which can stand as new reasons for believing in the deep origin of the ores, an explanation long since offered by Owen and Percival. Neither have we attempted to introduce positive demonstration in opposition to it. The question seems to be very much *in statu quo*, and, so long as it so remains, the old objections hold good and must be done away with before a change of opinion is warrantable. ARTHUR WINSLOW.

EDITORIAL.

THE Lake Superior excursion, under the leadership of Professors Van Hise and Wadsworth, which preceded the scientific meetings at Madison and Chicago, was participated in by a goodly company of foreign and American geologists from whose testimony we learn that it was unusually profitable and enjoyable. It was thoroughly planned, even to minor details, and carried into execution with remarkable precision, no time being wasted by errors or by undue attention to trivial features. Brief lucid explanations by the guides brought out the essential features of the formations and greatly facilitated observation.

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THE meeting of the Geological Society of America at Madison was attended by somewhat larger numbers than usually gather at a summer meeting. The following twenty papers were offered and read in full or given in substance, with the exception of two, whose authors were absent, and which were only read by title for lack of time: On the Study of Fossil Plants, by Sir J. Wm. Dawson; On a New Species of *Dinichthys*, On a new *Cladodus* from the Cleveland Shale, and On a Remarkable Fossil Jaw from the Cleveland Shale, by E. W. Claypole; Origin of Pennsylvania Anthracite, by J. J. Stevenson; The Magnesian Series of the North-western States, by C. W. Hall and F. W. Sardeson; On the Succession in the Marquette Iron District of Michigan, by C. R. Van Hise; Extra-morainic Drift in New Jersey, by G. Frederick Wright; On the Limits of the Glaciated Area in New Jersey, by A. A. Wright; South Mountain Glaciation, by Edward H. Williams, Jr.; Terrestrial Subsidence South-east of the American Continent, by J. W. Spencer; Evidences of the Derivation of Kames, Eskers, and Moraines of the North American Ice-sheet, chiefly from its Englacial Drift, and The Succession of Pleistocene Formations in the Mississippi and Nelson River Basins, by Warren Upham; The Cenozoic History of Eastern Vir-

ginia and Maryland, by N. H. Darton; Notes on the Geological Exhibits of the World's Fair, by G. H. Williams; Dislocation of the Strata of the Lead and Zinc Region of Wisconsin and their Relation to the Mineral Deposits, with some observations upon the Origin of the Ores, by W. P. Blake; Geology of the Sandhill Region in the Carolinas, by J. A. Holmes; The Gravels of the Glacier Bay in Alaska, by H. F. Reid; The Arkansas Coal Measures in their Relation to the Pacific Carboniferous Province, by James Perrin Smith; Glaciation of the White Mountains, N. H., by C. H. Hitchcock.

Professor Reid's paper on the Gravels of Glacier Bay was given the form of an illustrated evening lecture, and was found entertaining and instructive by the popular audience as well as the members of the society. By admirable photographic illustrations he brought forth very clearly and impressively many of the features of glacial action. It was peculiarly valuable as illustrating the behavior of alpine glaciers when they reach unusual magnitude, and particularly when they approach the Piedmont type.

The paper of Sir J. Wm. Dawson does not admit of ready synopsis. It needs to be read in full. Professor Claypole presented a number of interesting and apparently important facts relative to fossil fishes from north-eastern Ohio.

One of the more notable papers was that of Professor Stevenson, in which objections were urged against the current doctrine of the origin of anthracite through metamorphic agencies connected with heat and pressure. In lieu of this hypothesis, which the author held to be untenable, an hypothesis was offered connecting the origin of anthracite with the conditions of deposition. Anything less than a full statement of the author's view in his own language would fail to do it justice.

The paper of Professor Hall and Mr. Sardeson, read by the latter, endeavored to correlate, in much detail, the series of magnesian limestones of the north-western states. The most notable feature was the placing of the dividing horizon between the middle and the upper Cambrian considerably higher than has been done by most previous writers, throwing the larger part of the

light-colored sandstones that lie below the alternating series into the middle rather than the upper division.

Professor Van Hise gave a lucid sketch of the succession of deposits in the Marquette district and the grounds on which his interpretation is based. The paper showed the steady progress that is being made in the disentanglement of the gnarled structure of that region.

The papers of the Professors Wright awakened special interest from their relation to previously controverted ground. Contrary to their recent contention, they now extend the glaciated area so as to include the localities of High Bridge and Pattenburg and a considerable territory in the Triasic region essentially as maintained by Professor Salisbury before the Professors Wright took up the special study of the matter, though this was not as distinctly acknowledged as might have been desired. The discussion on the part of Chamberlin and McGee took the congratulatory form in view of the removal of one important point of difference and the advance toward harmonious views. It was noted that the points of difference were essentially reduced to two: The correlation of the Trenton gravels and the age of the extra-morainic drift relative to the moraine. In regard to this last it was pointed out that an important contribution had been made, unwittingly perhaps, to the presumption of great difference in the ages of the two drifts, in the fact that the outer drift, especially at such localities as High Bridge and Pattenburg, where it is thick, could not be presumed to be of the same age and character as that of the moraine and moraine-bordered drift, or its glacial origin would not have been previously denied by the Messrs. Wright, and that its age must be presumed to be very much greater or it could not have been referred to a residuary origin, especially to residuary derivation from formations which have disappeared from the neighborhood, since the moraine and moraine-bordered till are very distinctly characterized glacial formations of fresh aspect, while residuary accumulations and residuary topography are inherently expressions of age.

Dr. Spencer submitted a large mass of valuable data relative

to submerged channels in the south-eastern part of the continent, particularly the Antillean region, and urged these as evidences of very great subsidence. The paper awakened considerable discussion, the general tenor of which was the acceptance of the evidence and of the inference of subsidence, with an expression of doubt as to the time of its occurrence and its relations to other geological events.

The paper of Mr. Upham was a fuller statement of the arguments he has recently advanced in support of the derivation of kames, eskers, and moraines chiefly from englacial drift. These, and his views of the internal movement of the ice upon which they are in some degree founded, were opposed by Reid on physical grounds and by others on observational grounds. It was remarked that existing glaciers fail to show basally-rubbed material on their surfaces, even on their low terminal slopes, at least as a common fact. In his second paper, Mr. Upham urged a somewhat simple and brief succession of Pleistocene formations. The successive lines of moraines and the observed overlaps of till were interpreted as signifying minor and relatively brief halts and readvances of the ice. In the discussion, this position was opposed as being inconsonant with the evidences of interglacial intervals and of intervening erosions, oxidations and other changes which the formations were thought to present.

The papers of Darton and Holmes on different but analogous portions of the coastal region showed the very great advances which have been made in the last few years in the analysis and differentiation of the coastal formations, and the interesting discussions they called forth showed, in some measure, the important bearing these have upon the interpretation of the Pleistocene and immediately Pre-Pleistocene histories of the glaciated region.

Professor W. P. Blake, while coinciding in general in the views held by Whitney and by Chamberlin respecting lead and zinc deposits, urged the existence of a greater amount of dislocation than they had recognized, and attributed to it greater influence in the localization of the deposits. His views are intermediate

between those of the authors mentioned and those recently advanced by Mr. Jenney.

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THE attendance upon the meeting of the American Association was less than usual, but the interest and the character of the papers compared favorably with those of other sessions. The provisions made by the local committee were excellent, and the hospitalities extended by the citizens of Madison were graceful and generous. The exceptional beauties of the place and the superb weather lent attractiveness to the occasion.

In the Geological Section, the following papers were offered, and, with few exceptions, read in full or in substance: Gravels of Glacier Bay, Alaska, with lantern illustrations, by H. F. Reid; Use of the Name "Catskill," by John J. Stevenson; Section across the Coastal Plain Region in Southern North Carolina, by J. A. Holmes; Notes on Further Observations of Temperature in the Deep Well at Wheeling, W. Va., by William Hallock; Recent Investigations in the Cretaceous Formation on Long Island, N. Y., by Arthur Hollick; Character of Folds in the Marquette Iron District, by C. R. Van Hise; The Fossil Sharks of Ohio, by E. W. Claypole; Hillsdale County Geology, by Horatio P. Parmelee; Exhibition of Trilobites, showing Antennæ and Legs, by Chas. D. Walcott; Remarks on the genus *arthrophycus* Hall, On the Value of Pseudo-algæ as Geological Guides, Studies in Problematic Organisms, and The Genus *Fucoides*, by Joseph F. James; Northward Extension of the Yellow Gravel in New Jersey, Staten Island, Long Island and Eastward, by Arthur Hollick; Some Questions Respecting Glacial Phenomena about Madison, by T. C. Chamberlin; Amount of Glacial Erosion in the Finger Lake Region of New York, by D. F. Lincoln; Ice-sheet on Newtonville Sandplain, by F. P. Gulliver; Additional Facts Bearing on the Question of the Unity of the Glacial Period, by G. Frederick Wright; Changes of Drainage in Rock River Basin in Illinois, by Frank Leverett; Graphic Comparison of post-Columbia and post-Lafayette Erosion, by W J McGee; An Illustration of the Effect of Stagnant Ice in Sussex Co., N. J., and A Phase of Superficial Drift, by R. D. Salisbury;

Tertiary and Quarternary Stream Erosion of North America, by Warren Upham; The Emergence of Springs, by T. C. Hopkins.

As the writer was unable to hear a considerable number of these papers his notes must be confined to comparatively few of them. The paper of Mr. Lincoln presented a very interesting sketch of the quite remarkable evidences of glacial erosion and modification of surface in the Finger Lake region of New York. He showed, successfully we think, that the existing topography could not have arisen in its present form through the agency of subaërial degradation alone nor by the simple deposit of drift material on a surface so produced, but that a very notable amount of reshaping of the rock-surface was the result of glacial abrasion.

Mr. Frank Leverett made a quite important contribution to the data bearing upon the stages and duration of the earlier glacial epoch. He has recently discovered evidence that the Rock River formerly flowed nearly due south from a point near Rockford into the Green River basin, and presumably onward to the great bend of the Illinois River, near Hennepin, where an old deep channel exists. From this course the river was diverted to its present south-westerly course by the earliest or at least one of the earlier stages of the ice invasion of that region. Between the time of this diversion and the stage at which the kettle moraine was formed across the Rock River about forty miles to the north, near Janesville, Wis., the river cut a trench in rock across a succession of preglacial cols to maximum depths estimated at 100 to 125 feet. Mr. Leverett made careful estimates of the total amount of rock excavation and found it to amount to one square mile 1100 feet deep. Stated in another form, this equals a trench 100 feet deep, one mile wide and eleven miles long, or one-half mile wide and twenty-two miles long. After the trench had been cut, the glacial wash from the outer edge of the kettle moraine partially filled the trench as shown by remnants of terraces still existing at different points along it. The amount of this filling within the area of the above computation is estimated as one square mile 900 feet thick or $\frac{9}{11}$ of the amount of rock excavation. Since the formation of these gravels the

stream has only partially removed this partial filling of the trench previously cut. The estimated amount of the material so removed since the time of the formation of the kettle moraine is one square mile 650 feet deep, or $\frac{13}{22}$ as much as the *rock* excavation. From this it appeared that the amount of erosion in all post-glacial time (including the last of the glacial period), although wrought upon incoherent gravels, is much less than the amount of rock cutting accomplished between the time the river was diverted and the formation of the kettle moraine.

In the introduction to his paper Professor G. Frederick Wright stated that the hypothesis of an ice dam at Cincinnati appeared to be in a damaged condition, as an agency to account for the high terraces of the upper Ohio and some of its tributaries, and that it was a part of the purpose of the paper to repair the damage. It proved in the sequel, however, an effort at emendation by substitution. The additional facts bearing upon the unity of the glacial period cited in the paper related chiefly to a considerable depth of glacial wash in the trench of a tributary of the Beaver River near Homewood, Pa., just outside but near the border of the glaciated region. Professor Wright contended that the trough in which this glacial material lies must have been eroded previous to its deposition. This erosion he referred to pre-glacial times. The filling reaches nearly or quite to the upper terrace plain on the north side of the tributary, but does not appear on the terrace plain south of the tributary. In the course of his paper, and notably in the discussion following, Professor Wright advanced the hypothesis that the rock shelves which constitute the base of the high terraces of the upper Ohio, Allegheny and adjacent rivers, were formed during a stage of base-levelling in Tertiary times, that the narrower and deeper valley below the rock shelves (in round numbers 300 feet deep) was cut in this base-plane during a stage of elevation just preceding the glacial period, and that this trench was filled up with glacial wash and glacio-natant material to a height, at some points, as much as sixty feet above the rock shelves. In the discussion it was pointed out that, to

account for the fact that the trains of gravel that rise on the outer face of the adjacent moraines run down through this narrower deeper valley at low levels, it is necessary to suppose that there was an interruption of glacial action and a period of excavation during which the previously formed 300 feet or more of glacial wash was very largely carried away, and that this means a discontinuity of glacial action and an interglacial interval. The hypothesis is, therefore, not a contribution to unity but to discontinuity. The amount of excavation between the time of the supposed first filling of the trench and the partial refilling at the time of the formation of the adjacent terminal moraine was several times greater than all that has taken place since the moraine was formed. It signifies, therefore, a very notable interruption of continuity and a reversal of action. It may be here added that, logically, it also means the abandonment of the "fringe" theory to account for the older drift, for the filling of the valleys for so great distance and to so great depth means more than a trivial stage of advance, and the excavation previous to the formation of the moraine means more than a slight stage of recession.

Mr. Leverett has examined the Homewood locality since the meeting, and became satisfied that the partial filling of the trench at that point took place contemporaneously with a moraine which crossed the valley only a short distance above (some miles outside the glacial boundary as mapped by Lewis and Wright, and even some distance beyond the striæ not long since reported by Dr. Forshay, Mr. Leverett finding striation half a mile farther down the valley). The characteristics of this moraine seem to Mr. Leverett to indicate that it belongs to the group formed during the later incursion. The shelf of rock south of the tributary was not covered by the glacial wash of this stage because the trench lacked about twenty feet of being filled by the wash. Mr. Leverett found other remnants which he regards as parts of the same glacial flood-deposit farther down the Beaver, the surface rapidly descending as is the habit of such moraine-headed terraces near their sources. The facts

here, therefore, appear to be essentially the same as on other tributaries of the region which are crossed by the group of later moraines, and which seem to indicate profound excavation between the earlier and later drifts.

The hypothesis advanced in the paper, while not new in itself, having been among the multiple working hypotheses used by one or more students of the region, though not so far as known adopted by any one previously, is much more deserving of serious consideration than its predecessor, the Cincinnati ice dam. It may have some elements of truth in it, *i. e.*, a portion of the excavation of the rock below the old base-plane may have preceded the incursion of the glacial wash and even the glacial period. If this should prove true the effect will be to extend the importance of the earlier glacial epoch and to reduce the time necessarily attributed to the interglacial interval of excavation. The glacial formations of the lower Ohio and adjacent regions, however, seem to indicate a more complex hypothesis than this, or any previously advanced, which shall take cognizance of more than one glacial episode previous to the formation of the well-developed terminal moraines.

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ONE session of the Geological Section was adjourned to permit members to listen to papers read before the Anthropological Section having a geological bearing. These were the "Evidence of Glacial Man in America," by G. Frederick Wright; and "The Antiquity of Man in America," by W J McGee. The former consisted essentially of a restatement of the supposed evidences of the existence of man contemporaneously with the glacial period found in the terraces at Madisonville and Newcomerstown in Ohio, and at Trenton, N. J. The latter consisted essentially of a discussion of the character of evidence required for the establishment of the antiquity of man. Emphasis was especially laid upon the distinction between legal evidence and scientific evidence.

In the first paper no new discoveries were announced nor any additional data of note added to previous evidence. On

the other hand, the localities of Little Falls, Minn., Medora, Ind., and Loveland, Ohio, which have recently been urged as offering evidence of glacial man, were passed in silence. The paper referred constantly to the chipped stones as "paleolithic implements," and ignored the recent issue raised by Professor Holmes' investigations which are thought by many to make it probable that, whatever their geological age, the chipped stones are rejects and failures incident to the process of neolithic manfacture, and are therefore neither "paleolithic" nor "implements" in the proper sense of the terms. In the discussion, attention was called to the significant omission of three out of six of the localities which a year ago were urged as furnishing evidence of glacial man. Attention was called to the Ohio exhibit in the Anthropological Department of the Exposition in Chicago as furnishing proof that the testimony relating to the Newcomerstown locality cannot be accepted as having scientific value, because the point marked upon the photographs of the exhibit as being the location of the find cannot be rationally supposed to be the actual locality. Considerable discussion also turned upon the possibilities of intrusion, particularly through the agency of the growth and decay of the roots of successive generations of forests. It was urged that, allowing not more than six thousand years since the close of the glacial period, and allowing one hundred years for a generation of trees, sixty generations may have grown in succession. In the process of the growth of the large roots of the trees, the gravels and other material were pressed laterally and to some extent upward by their expansion, and on the decay of the roots the space they occupied was refilled, presumably from above, in part at least. In the case of trees which have tap roots the penetration is deep, particularly on gravel terraces where the substratum is porous and relatively dry and the ground-water far below the surface. It was urged that, in the refilling of the numerous tubes formed by the growth and decay of the roots of so many generations of trees, opportunities would be afforded for the occasional and sometimes deep penetration of relics that were originally

deposited at or near the surface. It was objected that the tubes formed by roots would be closed in by lateral creep and not from above. This, it may be here remarked, would depend upon whether the lower part of the root decayed before the upper part, or whether the decay proceeded from the surface downward. It would also depend upon whether the exterior of the roots rotted first or whether the bark resisted decay longest, leaving the interior, at a certain stage, practically hollow. It would appear that this subject has not received adequate attention, and that careful investigations respecting the growth and decay of roots in such situations should be made, and the possibilities of intrusion by means of them carefully determined. Reference was also made to the possibilities of intrusion through the agency of a similar succession of generations of burrowing animals. In view of the fact that in the paper under discussion only about twenty flaked stones of artificial origin were insisted upon as occurring deep within the gravels, the question of the possibilities of intrusion assumes very considerable importance. A certain amount of intrusion can fairly be claimed as probable. The vital question is, Can it be presumed to account for all cases not otherwise accounted for?

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THE admirable address of the retiring President of the American Association, Dr. LeConte, appears in this number of the JOURNAL and needs no comment. We hope to publish Vice-President Walcott's address in our next number.

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THE Woman's Section of the Geological Congress at Chicago, assembled on Monday, August 21, and held short sessions throughout the week. The following is the list of papers:

Methods of Teaching Geology, by Miss Mary Holmes, Ph.D., Rockford, Ill.; Physical Geology, by Miss Mary K. Andrews, Belfast, Ireland; Chemical Geology, by Miss Louise Foster, Boston, Mass.; Granites of Massachusetts and Their Origin, by Mrs. Ella F. Boyd, Hyde Park, Mass.; Artistic Geology, by

Mrs. S. Maxon-Cobb, Boulder, Colo.; The Geology of Ogle County, by Mrs. C. M. Winston, Chicago; The Fossils of the Upper Silurian, by Mrs. Ada D. Davidson, Oberlin, Ohio; Crinoidea and Blastoidea of the Kinderhook Group as found in the Quarries near Marshalltown, Iowa, by Jennie McGowen, A.M., M.D., Davenport, Iowa; The Evolution of the Brachiopoda, by Miss Agnes Crane, Brighton, England; The Mastodon in Northern Ohio; Post-Glacial or Pre-Glacial? by Miss Ellen Smith, Painesville, Ohio; Palæontology, by Miss Jane Donald, Carlisle, England; Glacial Markings, by Miss Thomson, Newcastle, England.

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THE general session of the Geological Congress convened at Chicago on August 24, immediately following the close of the meeting of the American Association at Madison.

The Congress was welcomed felicitously by the President of the Auxiliary, Charles C. Bonney, and briefly by the Chairman of the Committee on Organization.

Dr. A. R. C. Selwyn presided over the first session; Professor Joseph LeConte and Mr. Hjalmar Lundbohm, of Sweden, over the second session; and Professor James Hall and Dr. Groth, of Munich, over the third. The following papers were presented:

Pre-Cambrian Rocks of Wales, Dr. Henry Hicks, London, England; The Classification of the Rock Formations of Canada, with Special Reference to the Paleozoic Era, by Henry M. Ami, Geological Survey of Canada; The Cordilleran Mesozoic Revolution by Dr. A. C. Lawson, University of California; The Oil Shales of the Scottish Carboniferous System, by Henry M. Cadell, late of the Geological Survey of Scotland; Distribution of Pre-Cambrian Volcanic Rocks along the Eastern Border of the United States and Canada, by Professor George H. Williams, Johns Hopkins University; Huronian versus Algonkian, by Dr. A. R. C. Selwyn, Director Geological Survey of Canada; On the Migration of Material during the Metamorphism of Rock Masses, by Alfred Harker, St. John's College, Cambridge, Eng-

land; Wave-like Progress of an Epeirogenic Uplift, by Warren Upham, Geological Survey of Minnesota; Zur Nereiten Frage, by Dr. H. B. Geinitz, Dresden; Genetic Classification of Geology, by W J McGee, Bureau of Ethnology; The Extent and Lapse of Time Represented by Unconformities, by Professor C. R. Van Hise, U. S. Geological Survey; Restoration of Clidastes (illustrated), by Professor S. W. Williston, University of Kansas; Glacial Succession in the British Isles and Northern Europe, by Dr. James Geikie, Geological Survey of Scotland; Glacial Succession in Sweden, by Hjalmar Lundbohm, Geological Survey of Sweden; Glacial Succession in Switzerland, by Dr. Albrecht Heim, Zurich; Glacial Succession in Norway, by Dr. Andr M. Hansen, Geological Survey of Norway; The Succession of the Glacial Deposits of Canada, by Dr. Robert Bell, Canadian Geological Survey; Glacial Succession in the United States, by Dr. T. C. Chamberlin, University of Chicago; Pleistocene Climatic Changes, by Warren Upham, Geological Survey of Minnesota; Evidences of the Diversity of the Older Drift in North-western Illinois, by Frank Leverett, U. S. Geological Survey. A paper on the General Geology of Venezuela, by Dr. Adolph Ernst, was omitted on account of the illness of its author; and two papers by Dr. O. A. Derby, entitled, On the General Geology of Brazil, and On the Eruptive Phenomena of Brazil, were omitted because their author did not arrive until after the session. Four other papers announced were not read.

The latter part of the first session was devoted to a general discussion of the question, *Are there any Natural Geological Divisions of World-wide Extent?* The latter part of the second session was devoted to the question, *What are the Principles and Criteria to be observed in the Restoration of Ancient Geographic Outlines?* The general question assigned for the third discussion, *What are the Principles and Criteria to be observed in the Correlation of Glacial Formations in Opposite Hemispheres?* was omitted to give time for the discussion of the preceding glacial papers.

Several of the papers read will appear in this JOURNAL, and some of the matters touched upon in the discussions may be the

subjects of subsequent comment. About one hundred geologists were in attendance, a number which, under all the circumstances, was greater than was anticipated.

The afternoons of each day were devoted to the Exposition. Superintendent F. J. V. Skiff, Chief of the Department of Mines and Mining, and his associates, gave the members of the Congress a very pleasant welcome on their initial visit and provided special privileges of inspection that were heartily appreciated.

T. C. C.

REVIEWS.

Eruptive Rocks from Montana. By WALDEMAR LINDGREN. Proc. Cal. Acad. Sci. Ser. 2, Vol. 3. 1890.

A Sodalite-Syenite and other Rocks from Montana. By W. LINDGREN, with analyses by W. H. MELVILLE. Am. Jour. Sci. Vol. 45. April 1893.

Acmite-Trachyte from the Crazy Mountains, Montana. By J. E. WOLFF and R. S. TARR, Bull. Mus. Camp. Zoölogy, Harvard College. Vol. 16, No. 12. (Geological Series, Vol. 2).

Contributions to our knowledge of the mineral and chemical composition as well as the relationships of the igneous rocks of particular regions, however fragmentary, are of the greatest importance; especially when they relate to the vast areas of North America which remain almost unknown to the petrologist. The exploration of the great belt of country, one hundred miles wide, extending from California to Colorado and Wyoming along the fortieth parallel of latitude, by the geologists under Mr. Clarence King, constitutes the one great systematic study of the volcanic rocks of any considerable area on this continent. Less extensive investigations of smaller areas, isolated from one another and often separated by long distances, have been made from time to time, and to some extent have been published. But a large part of the work already done has not yet been printed. The facts so far brought to light show that the rocks of the Great Basin and the Pacific coast differ as a whole from those occurring in the eastern portion of the Rocky mountains and the region immediately east of it. This difference consists mainly in the greater abundance of the alkali-bearing rock-making minerals in the rocks of the latter region, caused by the relatively higher percentage of sodium or potassium in the magmas from which they have been derived.[1]

The recent papers by Mr. Lindgren and by Messrs. Wolff and Tarr illustrate this characteristic of the volcanic rocks of Montana along the frontal ranges of the Rocky mountains. All of the rocks described occur as intrusive bodies; laccolites, sheets, dikes or necks. They

[1] J. P. IDDINGS: The Origin of Igneous Rocks. Bull. Phil. Soc. Washington, Vol. 12, pp. 138, 139, 184.

were erupted in early Tertiary or late Cretaceous time in most cases, but their exact date is not known. Owing to extensive erosion the extrusive forms of these rocks, if they ever reached the surface, have been entirely removed.

Mr. Lindgren observes in the first paper cited that the rocks of this region appear to be more varied in chemical composition than the series usually found in the Great Basin; magmas rich in potassium are frequent, crystallizing as trachytes; often they are very basic, and contain much sodium, resulting in the abundant separation of such minerals as nepheline, sodalite and analcite.

The more or less acid rocks in the Little Belt mountains and at various points in front of the main range, west of Fort Benton, constitute dacites, hornblende-andesites, and diorites. Similar rocks also occur in the Moccasin mountains. They vary much in structure and composition, and form a natural group. The prevalent habit is porphyritic, but there appears to be a continuous series of transitions from porphyritic to fine granular rocks. The phenocrysts are feldspar and hornblende, and sometimes quartz and mica. The porphyritical feldspars are in part orthoclase in varying quantities, and there is reason to believe that these rocks pass by gradual transitions into trachytic and rhyolitic forms.

Those varieties free from phenocrysts of orthoclase and quartz grade into medium grained diorite, analogous to Stelzner's "Andendiorit," which contain besides plagioclase, hornblende and biotite, a little orthoclase and quartz as the last minerals to crystallize.

Of the more basic rocks, a part are syenites and trachytes, and a part basalts. The syenites which form dikes consist principally of orthoclase, plagioclase, biotite and a pyroxene, probably malacolite. They are called augite-syenites. The syenite from near Dry Fork, Little Belt mountains, contains, in addition to these minerals, allotriomorphic grains of an isotropic substance, probably sodalite. The rock contains 5.50 per cent. of K_2O, and 4.14 per cent. of Na_2O. The augite-syenite from the Highwood mountains is coarsely granular, and contains 5.66 per cent. of K_2O and 7.88 per cent. of Na_2O. This syenite is surrounded by trachytic and basaltic dikes; and in one case a dike of syenite was seen cutting one of the basaltic dikes.

The syenite from Square Butte at the northern end of the Highwood mountain is characterized by a noticeable percentage of sodalite and analcite, and has been called sodalite-syenite. Its chief constit-

uents are orthoclase, albite and hornblende. The relative proportions of the minerals has been estimated to be: orthoclase, 0.50; albite, 0.16; hornblende, 0.23; sodalite, 0.08; analcite, 0.03. The hornblende was analyzed and found to correspond to barkevikite. Mr. Lindgren calls attention to the resemblance in chemical composition between this rock and many nepheline-syenites, except for the relatively higher percentage of K_2O in the rock from Square Butte. He also notices the striking similarity between the analysis of this rock and those of certain leucitophyres from Rocca Monfina, and remarks that under different conditions the same magma, now crystallizing as a sodalite-syenite, might have produced a leucite-feldspar rock.

Trachytic rocks, with a great variety of habits, are abundant in the Highwood mountains. The essential minerals are sanidine and augite, with less prominent biotite. The augite is deep green, often somewhat pleochroic, and evidently contains an admixture of the ægirine molecule. It is very characteristic not only of the trachytes but also of the basaltic dike rocks of this region. These rocks form a connected series, the members of which differ in the relative quantities of augite and sanidine composing them. At one end of the series is a rock consisting almost wholly of feldspar, and at the other end a dark basaltic rock with porphyritical augites and a groundmass of sanidine and augite. In structure these rocks range from holocrystalline and granular to glassy. Some of the trachytes contain small crystals of sodalite (?) inclosed in sanidine. In one form of the rocks sanidine ceases to be the prominent phenocrysts and augite takes its place, and olivine occurs in the groundmass, which consists of feldspar and colorless glass easily soluble in HCl. Associated with the sodalite-syenite of Square Butte are dark colored basaltic rocks, which occur in three sheets at the base of the butte. Surrounding the butte there are numerous dikes apparently radiating from the central mass. One of these basaltic sheets contains phenocrysts of augite, olivine, brown mica, and white isometric crystals whose original character is uncertain. The rock is considerably decomposed. Another of the sheets is like analcite-basalt but is also decomposed. The third is coarsely granular and approaches theralite in composition.

The rocks described as analcite-basalts occur in dikes and possibly as necks in association with the rocks already described. They consist of augite, olivine, magnetite, and a mineral, which from its form and optical properties, and from its chemical composition appears to

be analcite. Biotite is sometimes present in small quantities. From the very fresh appearance of these rocks it seems probable that the analcite is a primary crystallization from the molten magma. The groundmass of the rock consists of augite and small crystals of analcite with magnetite. Mr. Lindgren calls attention to the difficulty of distinguishing glass, if present, from isotropic analcite.

In the Bear Paw mountains there are dikes of rocks related to those just described and which correspond to the lamprophyres of Rosenbusch. They are dark, fine grained, and porphyritic with phenocrysts of augite and long flakes of brown mica. The groundmass consists mostly of lath-shaped plagioclase, augite and mica. Some varieties with phenocrysts of olivine and augite, in a glassy groundmass without feldspar, approach certain limburgites.

The paper by Messrs. Wolff and Tarr is confined to a description of certain trachytic and syenitic rocks in the Crazy mountains. The first notice of the interesting rocks of this locality was published by Mr. Wolff in 1885, and he has since undertaken a much more extensive investigation of the same group of rocks, which is not yet completed. The trachytes form dikes, sheets and laccolites in the northern portion of the range, and are associated with theralite. Like the theralites and some other rocks of this range, they are coarse grained, almost granitic when in thick sheets, fine grained and porphyritic in the smaller sheets, dikes, and apophyses. When occurring in the latter forms the rocks have a trachytic habit, and are called acmite-trachyte. The phenocrysts are glassy feldspar, augite and small sodalites. Biotite is scarce. The feldspar is soda-microcline or anorthoclase. The augite is pale green at the center, and becomes dark green at the margin, where the optical characters are those of aegirine, similar to that in the theralite. The groundmass consists essentially of lath-shaped feldspar and acicular crystals of aegirine. With the green aegirine a few brown needles of acmite occur. There is a variable amount of interstitial matter between the feldspars of the groundmass which is probably nepheline in part, and partly analcite, derived from the alteration of the nepheline.

The coarse grained forms of the rock, or syenite, consist of the same essential minerals as the trachytic varieties. Sodalite is rare in the coarse rocks, and acmite is not always present. Chemical analyses of these rocks are published, but the discussion of them is postponed until the monograph of the whole group of rocks is pre-

pared. The resemblance between certain features of the rocks of Montana and those from Arkansas, described by J. Francis Williams, is pointed out by each of the writers cited. The resemblance to the lamprophyric rocks in the Absaroka range, Wyoming, east of the Yellowstone National Park, is also noticed.

Some of the petrographical characteristics of the rocks of this region are: The prevalence of orthoclase in many intermediate and basic rocks, leading to the frequent occurrence of trachyte and syenite and some forms of lamprophyre, as well as its presence in prominent crystals in the andesites and porphyrites, and the frequent occurrence of dark green augite and aegirine, and occasionally of acmite.

The difficulty of distinguishing colorless glass from isotropic analcite, both of which may occur in certain varieties of lamprophyre, makes it necessary to use the greatest care in determining the character of the apparent base in these forms of rocks. It seems probable to the reviewer that in some instances, in which an amorphous glass has been described as forming the matrix of the microscopic crystals in some lamprophyric dike rocks, it will be found that a definite isotropic alkali mineral is present, and that the rock is holocrystalline

JOSEPH P. IDDINGS.

THE

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GEOLOGIC TIME, AS INDICATED BY THE SEDIMENTARY ROCKS OF NORTH AMERICA.*

INTRODUCTION.

OF ALL subjects of speculative geology few are more attractive or more uncertain in positive results than geologic time. The physicists have drawn the lines closer and closer until the geologist is told that he must bring his estimates of the age of the earth within a limit of from ten to thirty millions of years. The geologist masses his observations and replies that more time is required, and suggests to the physicist that there may be an error somewhere in his data or the method of his treatment. The geologist realizes that geologic time cannot be reduced to actual time in decades or centuries; there are too many partially recognized or altogether unknown factors; but he can approximate the relative position of certain formations, and by comparison of their sediments, dimensions, and contained record of life with estimated rates of denudation, sedimentation and organic growth, form a general estimate of their relative time duration. It is my purpose to-day to take up the consideration of the evidence afforded by the sedimentary rocks of our continental area, and largely of a distinct basin of sedimentation, with a view of arriving, if possible, at an approximate time-period for their deposition. Before so doing, I will briefly refer to a few of the opinions that have been held by geologists on geologic

* Vice-Presidential address delivered before Section E, Am. Assc. Adv. Sci., Madison, Wis., August 17, 1893.

time and the age of the earth. Soon after geology emerged from its pre-systematic stage, in the latter part of the eighteenth century, and assumed an independent position among the inductive sciences speculations on the age of the earth began. Dr. James Hutton, the founder of modern physical geology, and the predecessor of Lyell, in advocating the uniformitarian theory, was the first to argue that the rate of destruction of one land area was the means of measuring the duration of others, and that the continents were formed of the ruins of pre-existing continents, but that in our measurement of time such periods were of indefinite duration.[1] It was not, however, until 1830, when Sir Charles Lyell published the results of his profound and philosophic studies of geologic phenomena, that the broad outlines of the law of uniformity, as opposed to the doctrine of geologic catastrophes, was fairly established. This work rendered possible a computation of the age of the earth on the principle that geologic processes were the same in the past as at present. He based his estimate of time on a rate of modification of species of mollusca since the beginning of the "Cambrian period," and divided the geologic series into twelve periods, assigning 20,000,000 years to each for a complete change in their species,—or 240,000,000 years in all. This estimate excluded the "antecedent Laurentian formation."[2]

The hour at our disposal does not permit of mentioning at length the views of other geologists. Dr. Charles Darwin thought that 200,000,000 of years could hardly be considered sufficient for the evolution of organic forms,[3] and Rev. Samuel Haughton assigned 1,280,000,000 of years to pre-Azoic time, and remarked that the globe was habitable, in part at least, for a longer period.[4] At a later date he estimated a minor limit to

[1] Theory of the Earth; or an Investigation of the Laws observable in the Composition, Dissolution, and Restoration of Land upon the Globe. Trans. Royal Soc. Edinburgh, Vol. I., 1788, pt. 1, p. 304.

[2] Principles of Geology, 10th Ed., Vol. I., 1867, p. 301.

[3] Origin of Species, American Ed., from 6th Eng. Ed., 1882, p. 286.

[4] Manual of Geology, 3rd Ed., 1871, p. 101.

geologic time of 200,000,000 of years.[1] Dr. James Croll estimated 72,000,000 years for the time duration since the first deposition of sedimentary rocks, while Sir Alfred R. Wallace thought that 28,000,000 years would suffice.[2] Of the value of this estimate he says: "It is not of course supposed that the calculation here given makes any approach to accuracy, but it is believed that it does indicate the order of magnitude of the time required."[3] Dr. Alexander Winchell reduced geologic time still more in his estimate of 3,000,000 years for the whole incrusted age of the world.[4] Later writers, however, do not accept this, as we find Sir Archibald Geikie concluding on the basis of denudation and deposition that the sedimentary rocks would have required 73,000,000 of years for their deposition, if denudation was at the rate of one foot in 730 years; or of 680,000,000 of years if at the slower rate of one foot in 6,800 years.[5] Mr. T. Mellard Reade adopted one foot in 3,000 years as the rate of average denudation throughout geologic time, and obtained a result of 95,000,000 of years as the time that had elapsed since the beginning of Cambrian time.[6] M. A. de Lapparent is one of the few European continental geologists that has written on geologic time. On the basis of mechanical denudation and sedimentation he thinks that from 67,000,000 to 90,000,000 of years would suffice, at the present rate of sedimentation for everything that has been produced since the consolidation of the crust.[7] The two most recent writers who have taken their initial datum point or "geochrone" from the consideration of late Cenozoic or Pleistocene phenomena

[1] Nature, Vol. 18, 1878, pp. 267–268.

[2] Stella Evolution and its Relations to Geological Time, 1889, pp. 48–49.

[3] Island Life, 2d. Ed., 1892, pp. 222–223.

[4] World Life, or Comparative Geology. Chicago, 1883, p. 378.

[5] Presidential Address; report of 62d meeting British Assoc. Adv. Sci., 1892, p. 21.

[6] Measurement of Geological Time. Geol. Mag., Vol. 10, 1893, pp. 99–100.

[7] De la mesure du temps parles phénomènes de sédimentation. Bull. Soc. Geol. France, 3d ser., Vol. 18, 1890, pp. 351–355. La Destinée de la terre férme et durée des temps geologiques. Revue des questions scientifiques, July, 1891. Pamphlet. Bruxelles. Pp. 1–38.

have differed materially in their results. Mr. W J McGee estimated that the mean age of the earth is 15,000 million years, and that 7,000 million had elapsed since the beginning of Paleozoic time.[1] In a subsequent note he modifies this conclusion and gives as a mean estimate 6,000 million years, of which 2,400 million have elapsed since the beginning of the Paleozoic. This is based on a minimum estimate of the age of the earth of 10,000,000 years and a maximum estimate of five million million (5,000,000,000,000) years.[2] Professor Warren Upham concludes that Quartenary time comprises about 100,000 years. He applies Professor Dana's time-ratio, and finds on this basis that the time needed for the earth's stratified rocks and the unfolding of its plant and animal life must be about 100 millions of years.[3]

From the foregoing estimates of geologic time the only conclusion that can be drawn is that the earth is *very old*, and that man's occupation of it is but a day's span as compared with the eons that have elapsed since the first consolidation of the rocks with which the geologist is acquainted.

When I began the preparation of this paper it was my intention to carefully analyze the sedimentary rocks of the entire geological series as exposed upon the North American continent. I soon found, however, that the time at my disposal would make this impracticable, and I decided to take up the history of the deposits that accumulated in Paleozoic time on the western side of our continent, in an area that for convenience I shall call the Cordilleran sea. This was chosen as (1) I was personally acquainted with many of its typical sections; (2) there was a broad and almost uninterrupted sedimentation during Paleozoic time; and (3) there is a prospect for obtaining more satisfactory data as a basis of calculation, since calcareous deposits are in excess of those of mechanical origin.

We will now consider certain points in relation to the growth

[1] American Anthropologist, Vol. 5, 1892, p. 340.

[2] Science, Vol. 21, 1893, p. 309.

[3] Am. Jour. Sci., Vol. 45, 1893, pp. 217–218.

or evolution of the North American continent, as the deposition of mechanical sediments depends to a considerable extent on the character of the adjoining land area, and chemical sedimentation is also influenced by it.

GROWTH OF THE CONTINENT.

The Algonkian sediments were deposited in interior and bordering seas that filled the depressions and extended over the margins of the American continent. From the great thickness of mechanical sediments it was evidently a period of elevated land and rapid denudation. With the close of Algonkian time extensive orographic movements occurred that outlined the subsequent development of the continent. The lines of the Rocky Mountain and Appalachian ranges were determined, and the great basins of sedimentation west of them defined. Subsequent movements have elevated the old and formed new sub-parallel ranges. These movements were often of long duration and also separated by great intervals of time, as is shown by the long-continued base levels of erosion during which the great thickness of calcareous deposits accumulated in the Cordilleran and Appalachian seas. Since Algonkian time the growth of the continent has been by the deposition of sediments in the bordering oceans and interior seas and lakes within the limits of the continental plateau; and it is considered that the relative position of the continental plateau and the deep sea have not materially changed during that period. How much the deposits on the continental border have increased its area is unknown, as at present they are largely concealed beneath the waters of the ocean. During Paleozoic time the two areas of greatest known accumulation were in the Appalachian and Cordilleran seas, where 30,000 feet or more of sediments were deposited. In the Cordilleran sea sedimentation was practically uninterrupted (except during a short interval in middle Ordovician time) until towards the close of Paleozoic time. In the northern Appalachian sea it continued without any marked unconformity, from early Cambrian to the close of Ordovician time, and, south of New York, with

relatively little interruption, until the close of Paleozoic time. Certain minor disturbances occurred along the eastern border of the sea, but they were not of sufficient extent to affect a general conclusion—which is, that the depression of the areas of deposition within the continental platform continued without reversal of the subsidence during Paleozoic time. During Cambrian, and it may be late Algonkian time, the extended interior Mississippian region was practically leveled by denudation, the eroded material being carried into the Cordilleran and Appalachian seas, and, probably, to a sea to the south.

The sedimentation of the Mississippian area in Paleozoic time, between the Appalachian and the Cordilleran seas, was small as compared to that which accumulated in the latter. In Devonian time there does not appear to have been any sedimentation in the western portion of it west of the 94th meridian and east of the Cordilleran sea, and it was slight in the same interval in the Appalachian sea south of the 37th parallel.[1] There is little if any evidence in the sediments of Paleozoic time to show that they were deposited in the deep, open ocean; on the contrary, they were largely accumulated in partially enclosed seas or mediterraneans and on the borders of the continental plateau. The former is particularly true of the sedimentation of the Cordilleran and Appalachian seas and the broad Mississippian sea.

The close of the prolonged period of Paleozic sedimentation was brought about by what Dana has termed the "Appalachian revolution." The topography of the continent was more or less changed, and the conditions of sedimentation that followed were unlike those that preceded. This revolution raised above the sea level a considerable portion of the Cordilleran and the Appalachian sea-beds and also of the Mississippian sea, east of the 96th meridian and north of the 34th parallel.

[1] The non-occurrence of Devonian sediment has not yet been fully explained. It has been suggested that the sea beyond the reach of mechanical sedimentation was too deep for the deposition of calçareous deposits. It is more probable that the sea was shallow and an area of non-deposition, or that its bed was raised to form a low, level land surface at a base level of erosion that was subjected to very slight degradation.

In its effect it may be compared to the Algonkian revolution[1] that preceded the deposition of the Paleozoic sediments.

With the opening of new conditions the sedimentation of Mesozoic time began upon the Atlantic border and over large areas of the western half of the continent with the deposit of mechanical sediments—sands, silts, etc.—during Jura-Trias time. They are of a character that naturally follows a period of disturbance of pre-existing conditions, and the formation of new basins of deposition with more or less elevated adjoining land areas. At its close orographic movements affecting the positions of the beds occurred upon the Pacific and Atlantic coasts, and also, to a more limited degree, throughout the Rocky mountain region. This does not appear to have extended over the plateau region or the central belt between the 97th and 105th meridians.

The Cretaceous formations have their greatest development between the 97th and 112th meridians in Mexico and the United States, in a broad belt which extends from the boundary of the latter to the northwest into the British Possessions as far as the 61st parallel. They were of a marine origin until towards the close of the period when a prolonged orographic movement elevated a large area of the continent above sea level, and locally upturned the Cretaceous strata in the Rocky mountain area. The shoaling of the sea was followed by the formation of great inland lakes, in which fresh water deposits succeeded the marine and estuarian sediments. Over the coastal regions they were of marine origin throughout.

The Tertiary sediments deposited on the Cretaceous are marine on the Atlantic, Gulf of Mexico, and Pacific coasts, and of fresh-water origin in the Rocky mountain and Great Plains areas—where they were deposited in the great inland lakes outlined in the previous period.

[1] The term revolution is used to describe the culmination of a long series of phenomena that finally resulted in a distinctly marked epoch in the evolution of the continent. The "Appalachian revolution" began far back in the Paleozoic, and culminated in the later stages of the Carboniferous and the Algonkian revolution, probably began far back in Algonkian time.

GEOGRAPHIC CONDITIONS ACCOMPANYING THE DEPOSITION OF PALEOZOIC SEDIMENTS IN THE CORDILLERAN SEA.

The assumed area of the Cordilleran or Paleo-Rocky mountain sea includes over 400,000 square miles between the 35th and 55th parallels. To the eastward during lower and middle Cambrian time a land area is thought to have extended from east of the 111th meridian across the continent to the Paleo-Appalachian sea. This land was depressed toward the close of middle Cambrian time, and the Mississippian sea expanded over the wide plateau-like interior region, from the Gulf of Mexico on the south to the Lake Superior region on the north; westward it penetrated among the mountain ridges between the 105th and 111th meridians, laying down the upper Cambrian deposits that are now found in New Mexico, Arizona, eastern Utah, the western half of Colorado, Wyoming, Idaho and Montana, and still farther north into Alberta and British Columbia. During Ordovician, Silurian, Devonian, and Carboniferous time this entire Mississippian region, except portions in Devonian time, appears to have been covered by a relatively shallow sea that was co-extensive with the Appalachian sea and that communicated freely with the Cordilleran sea. During this same age, however, the Rocky mountain area of New Mexico, Colorado, Utah, Wyoming and Montana formed a more or less well-defined boundary of ridges and islands between the Cordilleran and the interior sea up to the 49th parallel. To the north of the latter the conditions appear to have been the same as on the eastern side of the continent, where the Appalachian sea communicated freely with the Mississippian sea. From the data that we now have I think that the Paleozoic (Mississippian) sea extended at times over nearly all of the area subsequently covered by the Cretaceous and the later formations between the Gulf of Mexico and the Arctic ocean. This belt is bounded almost continuously on the east and west by Paleozoic rocks that extend from the Arctic ocean to Mexico, and whether of Cambrian, Ordovician, Silurian or Devonian age they carry essentially the same fauna throughout their extent. In the outcrops of lower strata that rise up

through this Cretaceous area, the Cambrian, Ordovician, and Carboniferous rocks are found encircling the pre-Paleozoic rocks. Instances in which the Archean rocks have been met with immediately beneath the Cretaceous in borings in Dakota and Minnesota are along the eastern border of the area, next to the Archean rocks,—where it is probable that the Cretaceous overlaps the Paleozoic to the Archean.

The western side of the Cordilleran sea seems to have been bounded by a land area that separated it from the Paleozoic sea, which extended through central California and the Pacific border of British Columbia and Vancouver's Island. From the positions of the Carboniferous deposits of California at the present time it appears that this land varied from 100 to 150 miles in width and was practically continuous along the western side of the Cordilleran sea. This view is further strengthened by the fact that the Carboniferous fauna of California has certain characteristics which are not found in the Carboniferous of the Cordilleran area. Our knowledge of conditions north of the 55th parallel is limited by the want of accurate geologic data. If Cambrian and Carboniferous rocks were not deposited in the Mackenzie river basin and also on the eastern side of the area now covered by Cretaceous strata, the inference is that during Cambrian and Carboniferous time there was a land area to the east and north of the northern Cordilleran sea that may have been tributary to the latter.

SOURCE OF SEDIMENTS DEPOSITED IN THE CORDILLERAN SEA.

The sediments deposited in every sea or lake are derived from land areas either by mechanical or chemical denudation.

Mechanical denudation results from the action of the waves and currents along the shore and the agency of rain, frost, snow, ice, wind, heat, etc., on the land. Rain is the most important factor, and the result depends mainly upon its amount and the slope or the gradient of the land. The general average of denudation for the surface of the land areas of the globe, now usually accepted, is one foot in 3,000 years. This varies locally,

according to Sir Archibald Geikie, from one foot in 750 years to one foot in 6,000 years.[1] Of the rate of denudation during Paleozoic time about the Cordilleran sea we know very little, but I think that it was relatively rapid in early Cambrian time and during the deposition of the arenaceous sediments of the Ordovician and Carboniferous. The material forming the argillaceous shales of the Cambrian and Devonian was supplied to the sea more slowly. These conclusions are sustained by the slight change in the character of the faunas where interrupted by the sands and pebbles of the Ordovician and Carboniferous and the marked change between the base and summit of the argillaceous shales. As a whole I think we are justified in assuming a minimum rate of mechanical denudation—of considerably less than one foot in 1,000 years—for the area tributary to the Cordilleran sea.

Chemical denudation is the removal of material taken into solution by water. Mr. T. Mellard Reade has discussed this phase of denudation in an admirable manner.[2] He came to the conclusion, from what was known of the volume of water discharged into the ocean per year, the average amount of material in chemical solution and the area of land surface drained by the rivers, that an average of 100 tons of rocky matter is dissolved per English square mile per annum. Of this he says: "If we allot 50 tons to carbonate of lime, 20 tons to sulphate of lime, 7 to silica, 4 to carbonate of magnesia, 4 to sulphate of magnesia, 1 to peroxide of iron, 8 to chloride of sodium, and 6 to the alkaline carbonates and sulphates we shall probably be as near the truth as present data will allow us to come."[3] By the use of the data given by Mr. John Murray, in a paper on the total annual rainfall on the land of the globe, and the relation of rainfall to the discharge of rivers,[4] I obtain 113 tons as the total

[1] Brit. Assoc. Adv. Sci., Sixty-second Meeting, 1893, p. 21.

[2] Proc. Liverpool Geol. Soc., Vol. III., pt. 3, 1877, pp. 212–235. Chemical Denudation in Relation to Geological Time, 1879, pp. 1–61.

[3] Loc. cit., p. 229.

[4] Scottish Geol. Mag., Vol. III., 1887, pp. 65–77.

amount of matter in solution discharged into the Atlantic basin per annum from each square mile of area drained into it. Of this 49 tons consist of carbonate of lime and 5.5 tons of sulphate and phosphate of lime.[1]

Mechanical Sediments.—With the geographic conditions described as prevailing during Paleozoic time, the source of mechanical sediments later than the Middle Cambrian must have been from the broken area on the eastern side that extended 100 to 200 miles to the eastward and to a much greater extent from the land along the western side of the sea. The enormous deposit of from 10,000 to 20,000 feet of mechanical sediments in early Cambrian time is explained by the assumption of favorable topographic conditions of denudation following the Algonkian revolution and the presence of a land area over the interior portion of the continent, and also, in all probability, between the western side of the Cordilleran sea and the western border of the continent. During this period the conformable pre-fossiliferous strata of the Cambrian accumulated and about 6,000 feet of the lower fossiliferous rocks as they occur in the Eureka district of central Nevada. Following the depression of the continent, which carried down the central area and also introduced the upper Cambrian (Mississippian) sea into the Rocky mountain area of Colorado, etc., there were deposited of mechanical sediments in central Nevada:

Ordovician sands,	500 feet.
Devonian fine argillaceous muds,	2,000 "
Lower Carboniferous sands,	3,000 "
Upper Carboniferous conglomerate and sands,	2,000 "
	7,500 "

making a total of 7,500 feet of mechanical sediments, the remaining portion of the section (15,150 feet) being limestone.

The following table exhibits the relative thickness of

[1] Total amount removed in solution per annum by rivers, 762,587 tons per cubic mile of river water. Total discharge of river water per annum into the Atlantic, 3,947 cubic miles. Area drained, 26,400,000 square miles. Amount of carbonate of lime per annum, 326,710 tons per cubic mile of river water; of sulphate and phosphate of lime, 37.274 tons.

mechanical and chemical deposits in the Cordilleran sea after the middle Cambrian subsidence:

	Wasatch.	Central Nevada.	Southwest Nevada.	Montana.	Alberta.
Mechanical Sediment, - -	10,000	7,500	2,500	1,000	4,600
Chemical Sediment, - -	10,400	15,150	13,000	4,000	15,000
Ratio, - - - - -	$\frac{1}{1}$	$\frac{1}{2}$	$\frac{1}{5}$	$\frac{1}{4}$	$\frac{1}{3}$

If an average is taken of the mechanical sediment deposited subsequent to the close of middle Cambrian time, it will be found to be about 5,000 feet for the entire area, which, I think, does away with any necessity to assume an additional hypothetical land area for the source of the mechanical sediment. The fine sand composing the quartzites and the silt forming the shales, as well as the fine conglomerate of later deposits, were derived from the adjoining land areas, and, in all probability, currents swept through from the ocean to the south or north, distributing the mud and sand contributed from the rivers and streams along the shores.

Chemical Sediments.—The present supply of the carbonate of lime, silica, etc., contained in sea-water is derived from waters poured into the sea by rivers and streams. The Cordilleran sea undoubtedly received a large contribution from the adjoining land areas, but a considerable amount was possibly derived from an oceanic current that circulated through it as the southern equatorial current of the Atlantic now sweeps through the Caribbean. From the vast deposits of carbonate of lime it might be assumed, *a priori*, that the waters of a Mississippi or Amazon were poured into it, but there is not any evidence of the existence of such a river, although the tributary area may have been very large in Cambrian and Carboniferous time, if the drainage of the country west of Hudson's Bay was to the westward.

Conditions of Deposition.—With free communication into the open ocean on the south, and probably on the north, during most of Paleozoic time strong currents must have circulated through the Cordilleran sea. The broad distribution of

mechanical sediments of a uniform character clearly shows this to have been the case, especially in pre-Silurian (Ordovician) time. The present known distribution of the mechanical sediments indicate that they were mainly brought into the sea from the west,[1] although a vast amount was derived from the land on the eastern side in pre-Ordovician time. They were quite evenly distributed over the sea bed, except where local accumulations of silt and sand occurred near the larger sources of supply, or in the direction of powerful currents within the sea.

The conditions of the deposition of the carbonate of lime are less clearly understood than those governing mechanical sediments, and I shall enter upon the discussion of them at considerable length. There are three methods by which it usually is considered that it may be deposited: 1. Agency of organisms; 2. Chemical precipitation; 3. By mechanical methods.

It is the general opinion of geologists that limestone rocks are the result almost entirely of the consolidation of lime removed from the sea water through the agency of life, and that they consist of the remains of foraminifera, crinoids, corals, etc., or their fragments, embedded in a more or less crystalline matrix resulting from subsequent alteration of the original deposits. This, however, has been seriously questioned. Sorby, in giving his general conclusions of an extensive microscopic examination of limestones, states that:

Even if it were possible to study in a detached state the finer granular particles which constitute so large a part of many limestone formations, it would usually be impossible to say whether they had been derived from organisms which can decay down into granules, or from other organisms which can only be worn down into granules, or from ground-down older limestone, or, in some cases, from carbonate of lime deposited chemically as granules. . . . . The shape and character of the identifiable fragments do, indeed, *prove* that much of this must have been derived from the decayed and-worn-down calcareous organisms;

[1] Geol. Expl. Fortieth Parallel, Vol. I., 1878, p. 247.

and very often we may reasonably *infer* that the greater part, if not the whole, was so derived; but, at the same time, it is impossible to *prove*, from the structure of the rock, whether some or how much was derived from limestones or earlier date, or was deposited chemically, as some certainly must have been.[1]

In their memoir on coral reefs and other carbonate of lime formations in modern seas, Messrs. Murray and Irvine show that temperature of the water has a controlling influence upon the abundance of species and individuals of lime-secreting organisms; high temperature is more favorable to abundant secretions of carbonate of lime than high salinity.[2]

Taking the samples of deep sea deposits collected by the Challenger as a guide, the average percentage of carbonate of lime in the whole of the deposit covering the floor of the ocean is 36.83; of this it is estimated that fully 90 per cent. is derived from pelagic organisms that have fallen from the surface water, the remainder of the carbonate of lime having been secreted by organisms that laid on, or were attached to, the bottom. The estimated area of the various kinds of deposits, the average depth, and the average percentage of carbonate of lime to each are shown in the following table:

TABLE showing the Estimated Area, Mean Depth, and Mean Percentage of $CaCO_3$, of the different Deposits.

Deposit.		Area square miles.	Mean depth in fathoms.	Mean per ct. of $CaCO_3$.
Oceanic Oozes and Clays	Red clay,	50,289,600	2727	6.70
	Radiolarian ooze,	2,790,400	2894	4.01
	Diatom ooze,	10,420,600	1477	22.96
	Globigerina ooze,	47,752,500	1996	64.53
	Pteropod ooze	887,100	1118	79.26
Terrigenous Deposits	Coral sands and muds,	3,219,800	710	86.41
	Other terrigenous deposits, blue mud, etc.	27,899,300	1016	19.20

Loc. cit., p. 82.

"We have little knowledge as to the thickness of these deposits, still such as we have goes to show that in these organic cal-

[1] Quart. Jour. Geol. Soc. London, Vol. 35, 1879, pp. 61–92.

[2] Proc. Roy. Soc. Edinburgh, Vol. 17, 1890, p. 81.

careous oozes and muds, we have a vast formation greatly exceeding in bulk and extent the coral reefs of tropical seas; they are most widely distributed in equatorial regions, but some patches of Globigerina ooze are to be found even within the Arctic circle in the course of the gulf stream."[1]

The percentage of carbonate of lime contained in deposits accumulating at different depths, as obtained from 231 samples collected by the Challenger, is shown in the following tabulation:

14	cases	under	500	fathoms,	m. p. c.	86.04
7	"	"	500 to 1000	"	"	66.86
24	"	"	1000 to 1500	"	"	70.87
42	"	"	1500 to 2000	"	"	69.55
68	"	"	2000 to 2500	"	"	46.73
65	"	"	2500 to 3000	"	"	17.36
8	"	"	3000 to 3500	"	"	0.88
2	"	"	3500 to 4000	"	"	0.00
1	"	"	4000	"	"	trace.

The fourteen samples under 500 fathoms are chiefly coral muds and sands, and the seven samples from 500 to 1000 fathoms contain a considerable quantity of mineral particles from continents or volcanic islands. In all the depths greater than 1000 fathoms the carbonate of lime is mostly derived from the shells of pelagic organisms that have fallen from the surface waters, and it will be noticed that these wholly disappear from the greater depths.[2]

By a series of experiments Messrs. Murray and Irvine found: "That although sea water under certain conditions may take up a considerable quantity of carbonate of lime in solution, yet it is unable permanently to retain in solution more than is usually found to be present in sea water, and it is owing to this that the amount of carbonate of lime is so constantly low. The reaction between organic matter and the sulphates present in sea water (to which we have referred) tends also to keep the amount of carbonate of lime in solution at about one-half (0.12 grms.) of what it might contain (0.28 grms. per litre). This peculiarity of sea water, in taking up a large amount of amorphous carbon-

[1] Loc. cit., pp. 82–83.

[2] Loc. cit., p. 84.

ate of lime and throwing it out in the crystalline form, accounts for the filling up of the interstices of massive coral with crystalline carbonate in coral islands and other calcareous formations, so that all traces may ultimately be lost of the original organic structure."[1]

The authors explain the disappearance of shells and lime deposits in the greater depths of the ocean by their being dissolved by the carbonic acid in the water, which is present in larger quantity at great depths and also is produced by the decomposition of the animal matter of the shell and of the various organisms living in the water and on the bottom. They conclude that:

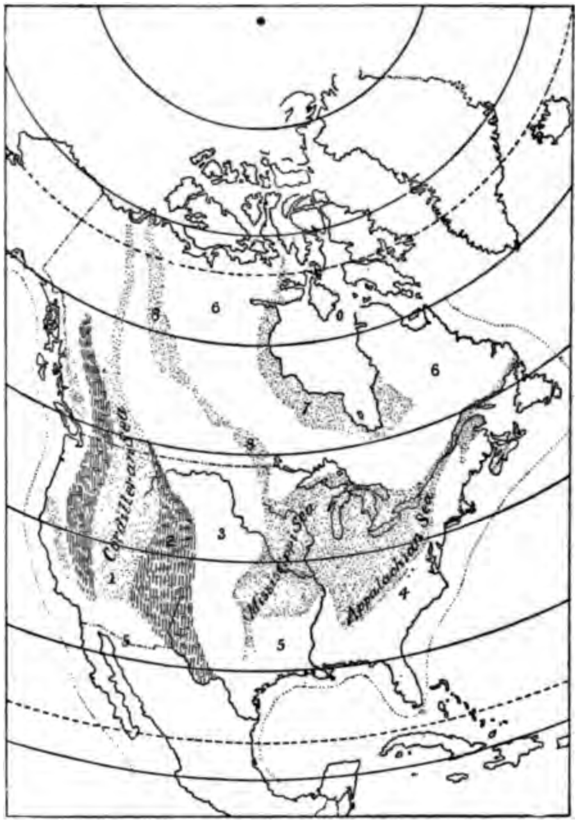
On the whole, however, the quantity of carbonate of lime that is secreted by animals must exceed what is re-dissolved by the action of sea water, and at the present time there is a vast accumulation of the carbonate of lime going on in the ocean. It has been the same in the past, for with a few insignificant exceptions all the carbonate of lime in the geological series of rocks has been secreted from sea water, and owes its origin to organisms in the same way as the carbon of the carboniferous formations; the extent of these deposits appears to have increased from the earliest down to the present geological period.[2]

In their report on deep sea deposits, collected by the Challenger Expedition, Messrs. Murray and Renard state that the chemical products formed in situ on the floor of the ocean nearly all originate in a sort of broth or ooze, in which the sea water is but slowly renewed. Many of them appear to be formed at the surface of the deposit—at the line separating the ooze from the superincumbent water, where oxidation takes place. In the deeper layers of the deposit a reduction of the higher oxides frequently occurs, and at the surface of the mud or ooze there are many living animals, as well as the dead remains of surface plants and animals.[3]

[1] Loc. cit., pp. 94–95.

[2] Loc. cit., p. 100.

[3] Report on the Scientific Results of the Voyage of M. M. S. Challenger. Deep-Sea Deposits, 1891, p. 337.



DESCRIPTION OF MAP.

On the map the hypothetical areas of the Cordilleran, Mississippian and Appalachian seas are clearly indicated. The land area west of the Cordilleran sea is numbered No. 1. The Californian sea and the area of Paleozoic deposits of western British Columbia No. 10. The northern extension of the Cordilleran sea (No. 9) is continued as the Paleozoic-devonian sea to the Arctic ocean. The early Cambrian land area (No. 2) east of the Cordilleran sea must have been more or less covered by water during later Paleozoic time. The area now covered by Mesozoic deposits, indicated by No. 3, was presumably covered by the westward and northward extension of the Paleozoic-Mississippian sea. The area east of the Appalachian sea is indicated by No. 4; and the supposed land barrier between the Hudson Bay and the Mississippian sea by No. 6; it is not improbable that during Ordovician or Silurian time a sea may have connected the two latter seas. The region to the south, indicated by No. 5, is supposed to have been covered by the southward extension of the Appalachian, Mississippian and Cordilleran seas. It is now covered by deposits of Mesozoic and Cenozoic seas.

A more detailed description of the map can be gained from the section on the growth of the continent and on the geographic conditions accompanying the different depositions of Paleozoic sediments in the Cordilleran sea.

They also conclude that practically all the carbon of marine organisms must ultimately be resolved into carbonic acid, the quantity of that acid produced in this way must be enormous, and cannot but exert a great solvent action not only on the dead calcareous structure, but also on the minerals in the muds on the floor of the ocean.[1] Of the effect of this destructive action, they say: "In all cases, however, calcareous structures of all kinds are slowly removed from the bottom of the ocean on the death of the organisms, unless rapidly covered up by the accumulating deposits, and in this way protected to a certain extent from the solvent action of the sea-water. It is evident from the Challenger investigations that whole classes of animals with hard calcareous shells and skeletons, remains of which one might suppose would be preserved in modern deposits, are not there represented; although they are now living in immense numbers in the surface waters or on the deposits at the bottom in some regions, yet all traces of them have been removed by solution. A similar removal of calcareous organic structures has undoubtedly taken place in the marine formations of past geologic ages.[2]

From the preceding statements it is evident that initially the greater part of the carbonate of lime is taken from the sea water by organic agency, but in the working over of this material in the chemical laboratory at the bottom of the sea a considerable portion is taken up by the sea water as amorphous carbonate of lime and thrown out in the crystalline form to form the matrix of the undissolved shells, etc.[3]

Mr. Bailey Willis has recently studied the question of the deposition of carbonate of lime, and states that "chemists describe two conditions under which bicarbonate of lime may be decomposed into neutral carbonate and carbonic acid: 1st, by diminution of the tension of the carbonic acid in the atmosphere; 2nd, by agitation of the solution."

[1] Loc. cit., p. 255.

[2] Loc. cit., p. 277. In this connection I wish to ask the student to read Messrs. Murray and Irvine's remarks on pp. 97-99, Proc. Roy. Soc., Edinburgh, Vol. 17, 1890.

[3] Proc. Roy. Soc., Edinburgh, Vol. 17, 1890, pp. 94-95.

"Theoretically either one of three things may occur to the neutral carbonate of lime, if it be thrown out of solution by either one of these processes. The carbonate may be redissolved, deposited as a calcareous mud, or built into organic structure." He studied some recent limestone deposited in the Everglades of southern Florida and found it to be formed of fragments of shells embedded in calcite. He states that, "Under the microscope the unaltered structure of the organic fragments is strikingly different from that of the coarse holocrystalline matrix, in which it is apparent that the crystals developed in place. Were this a limestone of some past geologic period it would be concluded, on the evidence of the crystalline texture of some parts of it, that it had been metamorphosed, and that the organic remains now visible had escaped the process which altered the matrix. But the observed conditions of its formation preclude the hypothesis of secondary crystallization."[1] Apparently the crystalline matrix is one primary product, and the calcareous mud is another, which being precipitated in the solution remains an incoherent sediment.

I think we may accept the conclusion that the deposition of carbonate of lime is by both organic agency and chemical precipitation. It is not necessary to speak of deposition by mechanical methods except in relation to the deposition of chemically derived granules. This probably takes place, and may be a very important factor in the formation of limestones in seas receiving a large supply of calcium from the land. Calcareous conglomerates do not enter as a prominent deposit in the Cordilleran area.

There is no evidence in the marine, geologic formations of this continent that they were deposited in the deep sea; on the contrary they are unlike such deposits and bear positive evidence of having been laid down in relatively shallow waters. Limestones with ripple-marks and sun cracks occur, and beds of ripple-marked sandstones alternate with shales and limestones. The more massive limestones, however, appear to have accumulated in deeper water. The conditions in the Cordilleran sea

[1] See Mr. Willis' article in Journal of Geology, Chicago, September, 1893.

were, I think, more favorable for rapid deposition than in the deep open ocean, but probably not as favorable as about coral reefs and islands. The limestones, and often the contained fossils, clearly indicate the presence of many of the same conditions of deposition as described by the authors I have quoted. More or less decomposed shells occur in nearly every limestone and a large proportion of limestone ; especially the non-metamorphic marbles clearly show that they were deposited under the influence of the agencies at work in the laboratory of the sea. Willis states that this occurs in the shallow waters of the Everglades of Florida, and there is no *a priori* reason why it did not occur throughout geologic time,—on the contrary, there is no doubt that it did.

Rate of deposit in former times.—It has frequently been assumed that in the earlier epochs the conditions were more favorable for rapid denudation, and in consequence thereof the transportation and deposition of sediment was greater. Professor Prestwich considers[1] that prior to the sedimentary rocks the land surface consisted of crystalline or igneous rocks subject to rapid decomposition owing to the composition of the atmosphere and to their inherent tendency to decay. They must have yielded to wear and removal with a facility unknown amongst mechanically formed and detrital strata where erosion operates. He thus accounts for one of the factors that gave the large dimensions and thicknesses of the earlier formations. Mr. Wallace thinks that geological change was probably greater in very remote times,[2] stating that all tellurac action increases as we go back into the past time, and that all the forces that have brought about geological phenomena were greater.[3]

[1] Geology, Vol. 1, 1886, pp. 60-61.

[2] Island Life, 2nd Ed., 1892, pp. 223-224.

[3] Sir William Thompson (Lord Kelvin), inferred from his investigations upon the cooling of the earth, that the general climate cannot be sensibly affected by conducted heat at any time more than 10,000 years after the commencement of the superficial solidification. Treatise on Natural Philosophy, Cambridge, 1883, Vol. 1, pt. 2, p. 478. Of the degree of the sun's heat we know so little that conjectures in relation to it have little force against the conditions indicated by the sedimentary rocks and their contained organic remains.

Dr. Woodward says, on the opposite view, that in the earliest geological periods each bed of sand, clay, limestone, etc., had actually to be formed, and that later deposits had the older sedimentary ones to furnish material, and, therefore, the newer deposits were laid down more rapidly.[1] This does not impress me strongly ; but from my experience among the Paleozoic rocks I agree with Sir A. Geikie, that "We can see no proof whatever, nor ever any evidence which suggests that on the whole the rate of waste and sedimentation was more rapid during Mesozoic and Paleozoic time than it is to-day.[2]

Professor Huxley, in his presidential address to the Geological Society of London in 1870, treats of the distribution of animals and says of his hypothesis that it "requires no supposition that the rate of change in organic life has been either greater or less in ancient times than it is now ; nor any assumption, either physical or biological, which has not its justification in analogous phenomena of existing nature."[3]

In the Grand Cañon of the Colorado, Arizona, there are 11,950 feet of strata of Algonkian age extending unconformably beneath the Cambrian. There is nothing in this section to indicate that the conditions of deposition were unlike those of the strata of Paleozoic and Mesozoic time. The sandstones, shales, and limestones are identical in appearance and characteristics with those of the latter epoch. The deposition of sulphate of lime and gypsum occurred abundantly in the upper portions of the series, and salt is collected by the Indians from the deposits formed by the saline waters issuing from the sandstone 8,000 feet below the summit of the series. The sandstone and shales were deposited in thin, even laminæ and layers, and the sun cracks and ripple marks give evidence of slow, uniform deposition. In the upper part of Chuar terrane there are 235 feet of limestone. And in one of the layers of limestone, 2,700 feet below the summit of the Chuar terrane, I find abundant evidence of the pres-

[1] Geol. England and Wales, 2nd Ed., 1887, p. 23.

[2] Rept. Sixty-second Meeting Brit. Assoc. Adv. Sci., 1892, p. 19.

[3] Quart. Jour. Geol. Soc., Vol. 26, 1870, p. lxiii.

ence of spiculæ of sponges, and what appear to be worn fragments of some small fossils. There is absolutely nothing to indicate more rapid denudation and corresponding deposition in this early pre-Cambrian series than we find in the Paleozoic, Mesozoic or Cenozoic formations.

PALEOZOIC SEDIMENTS OF THE CORDILLERAN SEA.

The great sections of sedimentary rocks in Arizona, Nevada, Utah, Montana, and in Alberta, B. A., all bear evidence that the sediments of which they are built up were deposited in a connected and continuous sea that extended from the vicinity of the 34th parallel, on the south, to the Arctic ocean on the north. Judging from the data now available, the width of this sea varied from 300 miles in Nevada to 500 miles on the line of the 40th parallel, and, with interruptions by mountain ridges, to 250 miles on the 49th parallel. It appears to have narrowed to the north in Alberta, British Columbia. Roughly computed, it covered south of the 55th parallel 400,000 square miles exclusive of any extension westward into northern-central California and southwestern Oregon and to the eastward over the area subsequently covered by the great interior Cretaceous sea. There is also an addition that might be made to allow for the contraction of the area by the later north-and-south faults and thrusts. Dr. G. M. Dawson estimates that in the Alberta and British Columbia area the width of the zone of the Paleozoic rocks has probably been reduced one-half by the folding and faulting, or from 200 to 100 miles.[1] This area assumed for the Cordilleran sea is on this account probably one-half less than it was before the Appalachian revolution.

The Wasatch section, on the eastern side of the area under consideration, has 30,000 feet of strata, of which 10,400 feet are limestone.[2] Further to the west, 250 miles W.S.W., at Eureka, Nevada, there 30,000 feet of strata in the entire section, and of this amount 19,000 feet are referred to limestone.[3] In the Pahranagat range and vicinity, 200 miles south of the Eureka section,[4]

[1] Bull. Geol. Soc. Am., Vol. 2, 1891, p. 176.

[2] Geol. Expl. Fortieth Parallel, Vol. 1, 1878, pp. 155-156.

[3] Mon. U. S. Geol. Survey, Vol. 20, 1892, p. 178.

[4] Loc. cit. pp. 186-200.

the limestones of the Paleozoic measure over 13,000 feet in a section of 13,500 feet. This section includes only 350 feet of the upper beds of the lower quartzite series, which is upwards of 11,000 feet in thickness in the Schell Creek range of eastern Nevada.[1]

On the eastern side of the area, in Montana, 300 miles north of the Wasatch section of Utah, the deposit of Paleozoic sediment is less in volume. Dr. A. C. Peale's section gives 3,800 feet of limestone in 5,000 feet of strata.[2] This does not include the 6,000 feet or more of sediments that occur below the fossiliferous Cambrian. I believe that the Paleozoic section will be found to be considerably thicker to the westward in Idaho. Continuing to the north 450 miles, the sections measured by Mr. R. G. McConnell, give 29,000 feet of Paleozoic strata, including 14,000 feet of limestone[3]. In a "Note on the Geological Structure of the Selkirk Range," Dr. Geo. M. Dawson describes a section containing upwards of 40,000 feet of mechanical sediments, which he refers largely to the Cambrian[4].

The Paleozoic limestones extend to the north, on the line of the eastern Rocky Mountains, to the Arctic ocean. In latitude 55° to 60° N. the Devonian limestones are over 2,500 feet in thickness, and there other still lower Paleozoic rocks that have not yet been studied in detail. The Devonian limestones extend 700 miles in the valley of the Mackenzie, from Great Slave Lake to below Fort Good Hope.[5] No Carboniferous limestones have been described from this region.

Tabulating the sections south from the 55th parallel and allowing for a great thinning out of the sediments in Idaho and Montana, we obtain an approximate general average of 21,000 feet of strata, of which 6,000 feet are limestone over an area estimated to include 400,000 square miles. Each square mile

[1] Geol. and Geog. Surveys West of 100th Merid., Vol. 3; Geology, 1875, p. 167.

[2] Author's manuscript.

[3] Geol. and Nat. Hist. Sur. Canada; Am. Rep., 1866, pp. 17, D–30 D.

[4] Bull. Geo. Soc. Am. Vol. 2, 1891, p. 168.

[5] Rept. Expl. Yukon and Mackenzie Rivers Basins, N. W. Terr. Geolo. & Nat. Hist. Sur. Canada, Vol. 4 (1888–'89), 1890, pp. 13 D–18 D.

includes 27,878,400 cubic feet of limestone for each foot in thickness and 167,270,400,000 cubic feet for a thickness of 6,000 feet, which, with an average of 12.5 cubic feet to ton, gives 13,381,-632,000 tons of limestone and impurities per square mile. The result of ten analyses of clear limestones within the central portion of area gives an average of 76.5 per cent. of carbonate of lime.[1] Taking 75 per cent. as the proportion of pure carbonate of lime (after deducting 50 per cent. to allow for arenaceous and argillaceous material in partings of strata, etc.), there remain 5,018,112,000 tons per square mile; multiplying this by 400,000 the result gives the number of tons of carbonate of lime that were deposited in what we know of the Cordilleran sea in Paleozoic time, or 2,007,244,800,000,000 tons, or two billion million tons in round numbers.

The following mode of presentation of the above was suggested by Mr. Willis:

In order to proceed with a calculation of the period required to form this thickness of 15,000 feet of mechanical sediment plus 6,000 feet of calcareous sediment, it is necessary, 1st, to compute the cubic volumes of the sediments; 2d, to estimate the area from which they were derived; and, 3d, to divide the cubic contents of the sediments by this land area. The result thus obtained represents the depth of erosion required to furnish the whole deposit, from which we may estimate the time under different assumptions of the rate of erosion.

But if we express amounts in cubic feet or tons the figures pass all comprehension; therefore, to simplify the statement, it is well to use a mile-foot as the unit of volume, that is, the volume of one mile square and one foot thick. (1 mile-foot=.79 Kilometre-metres). This is equal to 223,000 tons, if 12½ cubic feet of limestone equal one ton.

Thus stated mechanical sediments covering 400,000 square miles and 15,000 feet thick contain 6 billion mile-feet (4,740 million Kilometre-metres); and calcareous sediments covering the same area and 6,000 feet thick correspond to 2 billion 4 hundred million mile-feet (1,896 million Kilometre-metres). In the calcareous sediments a liberal allowance of one-half may be made for arenaceous and argillaceous matter in the limestone and partings, and analyses of ten clear limestones within the central part of the area give a little more than 75 per cent. of carbonate of lime. Applying these reductions we get 900 million mile feet (711 million Kilometre-metres) of pure carbonate of lime.

DURATION OF PALEOZOIC TIME IN THE CORDILLERAN AREA.

Estimates from Mechanical Sedimentation.—The land area tributary to the Cordilleran sea was larger before the depression of

[1] Geol. Expl. Fortieth Par. Vol. 2; Mon. U. S. Geol. Survey, Vol. 20.

the continent, towards the close of middle Cambrian time than during subsequent Paleozoic time. It included a portion of the region to the eastward and probably a belt of land extending well towards the Pacific coast of the continental plateau. The interior (Mississippian) region, west of the 90th meridian, probably drained into the sea to the south, forming a Cambrian Mississippi river prior to middle Cambrian time. This limits the Cambrian drainage into the Cordilleran sea to an area estimated at 1,600,000 square miles. The average thickness of mechanical sediments deposited before upper Cambrian time is estimated at from 10,000 to 15,000 feet. Taking the minimum of 10,000 feet and the assumed drainage area of 1,600,000 square miles and the rate of denudation at one foot in 1,000 years, it would have required 2,500,000 years to carry to the sea and distribute the 10,000 feet of sediment. This means the deposition of .048 of an inch per year, which is very small if the supposed conditions of denudation and transportation were as favorable as the character and mode of occurrence of the sediments indicate. If one-fourth of an inch per year is assumed as the rate of deposition, the 10,000 feet of sediment would have accumulated in 480,000 years or, in round numbers, in 500,000 years, which increases the rate of denudation to one foot in 200 years.[1]

CAMBRIAN MECHANICAL SEDIMENTS.

Rate of erosion over land area of 1,600,000 square miles.	Time in years for erosion of 2,500 feet.	Rate of deposition over sea area of 400,000 square miles for strata 10,000 feet thick.
1 foot in 3,000 years, - -	7,500,000	1 foot in 750 years, or .016 inch per annum.
1 foot in 1,000 years, - -	2,500,000	1 foot in 250 years, or .048 inch per annum.
1 foot in 200 years - - -	500,000	1 foot in 50 years, or .24 inch per annum.

In view of the evidence of rapid accumulation contained in the strata themselves the most rapid rate of deposition here stated, namely, .24 inch per annum, is considered as the most probable.

[1] By Mr. Willis' method (*ante*, p. 662, foot note) the mechanical sediments of the Paleozoic age for the area under consideration corresponds to 6 billion mile-feet.

In dealing with the post-middle Cambrian mechanical sediments we have a somewhat different problem, but, as a whole, rapid deposition is indicated. For instance, the Eureka quartzite of the upper Ordovician is a bed of sandstone, varying from 200 to 400 feet in thickness, distributed over a wide area,—perhaps 50,000 square miles. It is made almost entirely of a white, clean sand that was deposited in so short an interval that the Trenton fauna in the limestone beneath it and in the limestones above it is essentially the same. The sand appears to have been swept rapidly into the sea and distributed by strong currents. The same is true of the 3,000 feet of the lower Carboniferous sand and the 2,000 feet in the upper portion of the Carboniferous, while the shales of the upper Devonian accumulated more slowly. In this connection we must bear in mind that during the long periods in which the calcareous sediments forming the limestones were being deposited, the tributary land areas were in all probability base-levels of erosion, and chemical denudation was preparing a great supply of mechanical material that, on the raising of the land, was rapidly swept into the sea and distributed. In this manner the time period of actual mechanical denudation was materially shortened, yet, on account of the manifestly slower deposition of the Devonian shales, the rate of denudation should be assumed as less than during Cambrian time.

In post-Cambrian time the area of the land surface was materially reduced by subsidence, which did not, however, greatly extend the Cordilleran sea, and it may fairly be estimated at 600,000 square miles. The depth of mechanical sediments already estimated is 5,000 feet, and their volume at two billion mile-feet. Dividing the volume by the area of erosion we get 3,300 feet as the depth of erosion required.

Again, applying different rates of erosion, with allowance for slow progress of degradation during Devonian time, we have:

Of this total the greater part, namely, two-thirds or 4 billion mile-feet, are of Cambrian age. Dividing this volume by the land area just given, 1,600,000 square miles, we get 2,500 feet as the depth of erosion during the formation of the Cambrian mechanical sediments. Assuming different rates of erosion we may obtain times differing as follows:

POST-CAMBRIAN MECHANICAL SEDIMENTS.

Rate of erosion over land area of 600,000 square miles.	Time required for removal of 3,300 feet.	Rate of deposition in sea of 400,000 square miles, for 5,000 feet of strata.
1 foot in 3,000 years, - -	9,900,000 years	1 foot in 1,980 years, or .006 inch per annum.
1 foot in 1,000 years, - -	3,300,000 years	1 foot in 660 years, or .09 inch per annum.
1 foot in 200 years, - - -	660,000 years	1 foot in 132 years, or .18 inch per annum.

The rate of one foot in 200 years is assumed as the most probable and 660,000 years as the time required for the removal and deposition of the 5,000 feet of post-Cambrian mechanical sediments.

There is one factor that may need to be taken into consideration in estimating the time duration of the deposition of the mechanical sediments of the Cambrian and pre-Cambrian of the northern portion of the Cordilleran sea that would materially lengthen the period. Dr. George M. Dawson describes the Nisconlith series, especially in the Selkirk range of British Columbia, as composed of "blackish argillite-schists and phyllites, generally calcareous, with some beds of limestone and quartzite, 15,000 feet."[1] It is correlated with the Bow River series, which contains, in the upper portion, the lower Cambrian fauna. The presence of these calcareous beds indicates a slower rate of deposition than we have estimated for the lower portion of the Cambrian series over the greater part of the Cordilleran sea; but as yet the correlation with the sediments of the Cordileran sea is not sufficiently well established to warrant our allowing a greater time period to the Cambrian on this account.

Estimates from Chemical Sedimentation.—We have estimated that the Paleozoic sediments of the Cordilleran sea contain 2,007,244,800 million tons (900 million mile-feet) of carbonate of lime, which was derived by organic or chemical agencies from the sea water to which it was contributed by the land. If oceanic circulation could be excluded from the problem we might pro-

[1] Bull. Geol. Soc. Amer., Vol. II., 1891, p. 168.

ceed directly to estimate the time required to obtain this amount of lime from the land area tributary to the Cordilleran sea. It may be well to make such an estimate on the basis that the area of denudation tributary to the Cordilleran sea in post-middle Cambrian time had 600,000 square miles from which 30,000,000 tons of carbonate of lime and 12,000,000 tons of sulphate of lime were derived per annum,[1] if we assume T. Mellard Reade's rate of erosion—of 50 tons of carbonate of lime and 20 tons of sulphate of lime per square mile per annum. If all of the 42,000,000 tons (equal to 18.8 mile-feet) per annum were deposited within the limits of the Cordilleran sea, it would have taken 47,790,000 years for the accumulation of the carbonate of lime now estimated to have been deposited in the Cordilleran sea. Such a result is manifestly a maximum based on the consideration of one set of phenomena. In addition, however, to this supply of calcium the geographic conditions appear to have been favorable to the free circulation of oceanic currents through the Cordilleran sea, and the temperature was favorable to extensive evaporation and to the development of organic life, as shown by the occurrence of corals in the middle and upper portions of the Paleozoic, from the Mackenzie river basin on the north to southern Nevada on the south. These conditions would reduce the time necessary for the deposition of the carbonate line.

Ocean water of the present time contains in solution 151.025000 tons of solid matter per cubic mile, which is divided among various salts. A comparison of the matter in the sea and river water shows that the sea contains 3.85 parts of magnesium to one of calcium, and river water contains three parts of calcium to one of magnesium. The silica and alumina of the river water disappears in sea water, while the sodium is accumulated. It is from these considerations and the fact that limestones are

[1] Messrs. Murray and Renard consider that organisms have the power of secreting the carbonate of lime from the sulphate of lime contained in the sea water by chemical reaction. For an account of the chemical action that takes place in the sea water, see report of the Deep-Sea Deposits of the Challenger Expedition.

so largely formed of carbonate of lime that I have taken the latter as a basis for estimates upon the rate of chemical sedimentation, an allowance being made for the presence of silica, alumina and magnesium in the limestones.

Rate of Deposition of Recent Deposits.—Of the rate of deposition in recent deposits Messrs. Murray and Renard state, in their report on the deep-sea deposits, that: "It must be admitted that at the present time we have no definite knowledge as to the absolute rate of accumulation of any deep-sea deposit, although we have some information and some indications as to the relative rate of accumulation of the different types of deposits among themselves. The most rapid accumulation appears to take place in the Terrigenous Deposits, and especially in the Blue Muds, not far removed from the embouchures of large rivers. Here no great time would seem to have elapsed since the deposit was formed, so far at least as the materials collected by the dredge, trawl, and sounding tube are concerned.

"Around some coral reefs the accumulation must be rapid, for, although pelagic species with calcareous shells may be numerous in the surface waters, it is often impossible to detect more than an occasional pelagic shell among the other calcareous debris of the deposits.

"The Pelagic Deposits as a whole, having regard to the nature and condition of their organic and mineralogical constituents, evidently accumulate at a much slower rate than the terrigenous deposits, in which the materials washed down from the land play so large a part. The Pteropod and Globigerina oozes of the tropical regions, being chiefly made up of the calcareous shells of a much larger number of tropical species, must necessarily accumulate at greater rate than the Globigerina oozes in extra-tropical areas or other organic oozes. Diatom ooze, being composed of both calcareous and siliceous organisms, has, again, a more rapid rate of deposition than the Radiolarian ooze, while in a Red Clay there is a minimum rate of growth." [1]

[1] Report on the scientific results of the voyage of H. M. S. Challenger; Deep-Sea Deposits. 1891, pp. 411-412.

Professor James D. Dana estimates that the rate of increase of coral reef limestone formations, where all is most favorable, does not exceed perhaps a sixteenth of an inch in a year, or five feet in a thousand years. Of this he says, "And yet such limestones probably form at a more rapid rate than those made of shells."[1]

Messrs. Murray and Irvine, in their valuable paper on coral reefs and other carbonate of lime formations in modern seas, calculate the total amount of calcium in the whole ocean to be 628,340,000 million tons; also they estimate that 925,866,500 tons of calcium are carried into the ocean from all the rivers of the globe annually. At this rate it would take 680,000 years for the river drainage from the land to carry down an amount of calcium equal to that at present existing in solution in the whole ocean. They say further: "Again, taking the 'Challenger' deposits as a guide, the amount of calcium in these deposits, if they be 22 feet thick, is equal to the total amount of calcium in solution in the whole ocean at the present time. It follows from this that, if the salinity of the ocean has remained the same as at present during the whole of this period, then it has taken 680,000 years for the deposits of the above thickness, or containing calcium in amount equal to that at present in solution in the ocean, to have accumulated on the floor of the ocean."[2] According to this calculation the mean rate of accumulation over existing oceanic areas is $\frac{22}{680000}$, or .000032 feet per annum.

Was the Deposition of Chemical Sediment More Rapid in Paleozoic Time?—It has been claimed that the quantity of lime poured into the ocean in earlier times was greater than during the later epochs of geological history,—this arising from the more rapid disintegration of the Archean, crystalline and volcanic rocks. It is undoubtedly a fact that the ocean was stocked in Archean and Algonkian time with matter in solution that produced salinity, but we have no evidence from chemical precipitation that more

[1] Corals and Coral Islands, 3rd Ed., 1890, pp. 396-397.

[2] Proc. Royal Soc., Edinburgh, Vol. 17, 1890, p. 101.

calcium was poured into it than could be retained in solution. The Laurentian limestones are crystalline, but, as has been shown, this texture is consistent with either chemical or organic origin. The unaltered limestones in the Algonkian rocks of the Colorado Cañon section show traces of life in thin sections, and they may be, to a great extent, of organic origin. There is no evidence in the texture, bedding or composition of these ancient limestones to indicate that they were deposited under conditions of salinity or of supply differing materially from those of the present, and I do not find that we have reason to believe that the deposition of the carbonate of lime was more rapid in the Paleozoic than during the Mesozoic and Cenozoic times, even though the supply from the land may have been greater. Where the conditions were favorable for the deposition of lime, as in the Cretaceous sea of northern Mexico, we find evidence of an immense accumulation of calcareous sediments. Of the amount of calcareous deposits in the seas outside of the continental areas that are not open to our inspection, we know nothing; but judging from the deposition that is going on to-day in the great oceans, the accumulation of calcareous sediment has gone on in the past as steadily and uninterruptedly as at present, subject to varying conditions of temperature, life, depth of water, etc.

Area of Deposition in Paleozoic Time. — We have no proof that the salinity of the sea or the amount of calcium contained in it has varied from age to age since Algonkian time. If it has not, all of the calcium poured into the ocean during 2,000,000 years would have about equaled the amount now contained in the limestones of that area. We have, however, to account for the calcium deposited in the interior Mississippian sea and the seas over other portions of this continent and other continental areas, and on portions of the floor of the ocean that are now accessible for observation. It is also to be considered that the land areas subject to denudation in Paleozoic time were, in all probability, of no larger extent than at the present time.

The area of dry land to-day is estimated to be 55,000,000 square miles, and of oceans 137,200,000 square miles.[1]

Mr. T. Mellard Reade estimates the area of the Paleozoic formations of Europe at 645,600 square miles in the total area of 3,720,500 square miles. His estimate of the Paleozoic area is of that which is exposed at the present time, and does not include that which is concealed beneath other formations. I think it will be a minimum estimate to consider that an equal area is covered by the later formations, which, with that exposed, would give in round numbers 1,290,000 square miles,—or one-third of the land area of Europe. In North America nearly one-half of the total area was covered by the Paleozoic sea; in South America it was considerably less; and we know too little of the Asiatic and African continents to place any estimate upon their Paleozoic areas. I think, however, if we take one-fourth of the present land area as the territory covered by the Paleozoic seas we shall be considerably within the actual amount, even if we add to the surface of the continents the margins of the continental platforms now beneath the sea. Deducting the one-fourth from the total land area, there remain 41,250,000 square miles as the land area undergoing denudation during Paleozoic time. It may be claimed that large areas in the archipelago region of the Pacific and in the Arctic ocean may have been land areas at that time. To meet this, 8,750,000 square miles may be added to the 41,250,000, giving a total of 50,000,000 square miles as the land area of Paleozoic time.

The estimated areas of the various deep sea deposits of to-day, containing a large percentage of the carbonate of lime, are as follows: Globigerina ooze, 49,520,000 square miles, mean percentage of carbonate of lime, 64.53; Pteropod ooze, 400,000 square miles, percentage of carbonate of lime, 79.26; Coral mud and sand, 2,556,000 square miles, mean percentage of carbonate of lime, 86.41. In addition to this, Diatom ooze covers an area of 10,880,000 square miles, with 22.96 percentage of carbonate of lime; and the mean percentage of carbonate of lime in the

[1] Dr. JOHN MURRAY: Scottish Geog. Mag., Vol. 4, 1888, p. 40.

Blue Mud and other terrigenous deposits that cover 16,050,000 square miles is 19.20. If we consider only those deposits containing over 64 per cent. of carbonate of lime, we have 52,500,000 square miles, over which there is at the present time a deposition of the carbonate of lime being made. We have roughly estimated that in Paleozoic time the area of the Paleozoic sea, in which deposits were being accumulated, was over 13,000,000 square miles. It does not appear that there is any good reason to suspect that the area of deposition of the carbonate of lime in the open ocean during Paleozoic time was not fully equal to that of the present time. Adding this area of 52,500,000 to the 13,750,000, we have over 66,000,000 square miles as the probable area in which calcium was being deposited in Paleozoic time.

Conditions favorable for a rapid deposition of the carbonate of lime.—The condition most favorable for the rapid accumulation or deposition of the carbonate of lime through organic or mechanical agency is warm water and a constant supply of water through circulation by currents; this is shown by the immense abundance of life where the margin of the continental plateau is touched by the Gulf Stream. Another favorable condition is the supply of carbonate of lime by river water directly into the ocean in the vicinity where the deposition of lime is going on either through organic or inorganic agencies. This is well illustrated by the conditions produced by the Gulf Stream. The oceanic currents, passing along the northeastern coast of South America, sweep the waters of the Amazon through the Caribbean sea into the Gulf of Mexico, where they meet the vast volume of water coming from the Mississippi. These are poured out through the narrow straits between Florida and Cuba and carried northward over the sloping margin of the continental plateau. Under such favorable conditions the deposit must be much greater than in areas where there is little circulation and the supply of calcium is limited to the average which is contained in sea water. If to the preceding there is added extensive evaporation within a partially enclosed sea, the rate of deposition of matter in solution will be largely increased.

The area over which calcareous depositions was going on during Paleozoic time we have estimated at 66,000,000 square miles, which includes the areas of the seas over the continental platforms and those of the surrounding oceans. As the conditions appear to have been more favorable for the deposition of lime in the Cordilleran aud Appalachian seas, we will assume that it was four times that of the open ocean.[1] With a land area of 50,000,000 square miles (*ante* p. 670) and a rate of chemical denudation of 70 tons per square mile per annum, the total calcium contributed to the ocean per year during Paleozoic time would be 3,500 million tons or 3.78 times as much as that estimated for per annum at the present time, which is 925,866,500 tons (*ante* p. 668). This would have provided 50.7 tons for deposition per annum per square mile in the 65,000,000 square miles of ocean and seas and 202.8 tons for deposition per annum per square mile in the 400,000 square miles of the Cordilleran and 600,000 square miles of similar seas. On this basis 81,120,000 tons (36.4 mile-feet) were contributed per annum from the ocean water to the deposit in the Cordilleran sea; adding to this the 42,000,000 tons (18.8 mile-feet) contributed per annum by the denudation of the surrounding area to the Cordilleran sea, we have 128,120,000 tons (55.2 mile-feet) as the amount available for deposit per annum in the Cordilleran sea. At this rate it would have required 16,300,000 years to have deposited the 2,007,244,800 million tons (900 million mile-feet) of *calcium* in the Cordilleran sea; adding to this the 1,200,000 years estimated for the deposition of the mechanical sediments, we have a total of 17,500,000 years as the duration of Paleozoic time.

In reviewing the preceding estimates we must consider that,

[1] Under the reduction of 50 per cent. for the interbedded and intermingled mechanical sediments and 25 per cent. for other material than calcium deposited from solution, the apparent amount of calcium deposited in the Cordilleran sea was greatly reduced. If this same ratio of reduction is applied to other Paleozoic limestone areas, I doubt if over 1,000,000 square miles will be found to contain as large an average amount of calcium per square mile as the Cordilleran area. On this account 1,000,000 square miles is the area taken for the greater rate of deposition of calcium during Paleozoic time.

throughout, I have increased the various factors above those usually accepted: thus, for mechanical sedimentation, one foot in 200 years is used. If the usually accepted average of one foot in 3,000 years is taken the time period must be increased fifteenfold (21,000,000 years), or the area of denudation from 1,600,000 square miles to 24,000,000—or three times the present area of the North American continent.

In the estimate for the amount of chemical denudation the largest average is taken—70 tons of calcium per square mile per annum—and the assumption made that all calcium derived from the adjoining drainage was deposited within the Cordilleran sea. Again, the total supply provided per annum to ocean waters of Paleozoic time is taken as 3.78 times greater than the amount annually contributed to ocean waters to-day; of this, four times as much is assumed to have been taken out per annum per square mile as was taken by the remaining area in which calcium was being deposited.

The area of the Cordilleran sea is given as 400,000 square miles, but it was probably 600,000, if not much more. It may be claimed that the area tributary to the Cordilleran sea was greater than I have estimated. The evidence, such as it is, is against such a view. As a whole I think the estimate of 17,500,000 years for the duration of Paleozoic time in the Cordilleran area is below the minimum rather than above it.

If the estimated rate of the deposition of coral limestones—five feet in 1,000 years—given by Prof. Jas. D. Dana is correct, the 19,000 feet of Paleozoic limestone in central Nevada would have required 3,800,000 years to have accumulated under the most favorable local conditions surrounding a coral reef. With the exception of large deposits of corals in Devonian rocks no appearance of a coral reef is recorded in the Cordilleran area.

TIME-RATIOS OF GEOLOGIC PERIODS.

The time-ratio adopted by Prof. James D. Dana for the Paleozoic, Mesozoic and Cenozoic periods is: 12, 3, and 1, respectively[1]. Prof. Henry S. Williams applies the term *geochronology*,

[1] Manual of Geology, 1875, p. 586.

giving the standard time-unit used the name *geochrone*. The geochrone used by him in obtaining a standard scale of geochronology is the period represented by the Eocene. His time-scale gives 15 for the Paleozoic; 3 for the Mesozoic; and 1 for the Cenozoic, including the Quaternary and the Recent.[1]

The Rev. Samuel Haughton obtained the following time-ratios from the maximum thickness of strata as they occur in Europe:

SCALE OF GEOLOGICAL TIME.

Period.	From Theory of Cooling Globe.	From Maximum Thickness of Strata.
Azoic	33.0 per cent.	34.3 per cent.
Paleozoic	41.0 "	42.5 "
Neozoic	26.0 "	23.2 "
Total	100.0 per cent.	100.0 per cent.

He draws from this the principle—"*The proper relative measure of geological periods is the maximum thickness of the strata formed during these periods.*"[2]

In considering the time-ratios for the Paleozoic, Mesozoic, and Cenozoic rocks of the North American continent, as given by Dana and Williams, I think that a too small proportion has been given to the Mesozoic and Cenozoic. In the Mesozoic of the western-central area occur the coal deposits of the Laramie series and the great development of limestone (from 10,000 to 20,000 feet) in the Cretaceous of Mexico. The limits of this paper do not permit of a discussion of the available data bearing upon geologic time-ratios; but from a comparison of the Paleozoic, Mesozoic, and Cenozoic strata and the geologic phenomena accompanying their deposition, I would increase the comparative length of the Mesozoic and Cenozoic periods so that the time-ratios would be: Paleozoic, 12; Mesozoic, 5; Cenozoic, including Pleistocene, 2.

DURATION OF POST-ARCHEAN GEOLOGIC TIME.

Taking as a basis 17,500,000 years for Paleozoic time and the time-ratios, 12, 5, and 2 for Paleozoic, Mesozoic, and Ceno-

[1] Journal of Geology, Chicago, Vol. I., 1893, pp. 294-295.

[2] Nature, Vol. 18, 1878, p. 268.

zoic (including Pleistocene) respectively, the Mesozoic is given a time duration of 7,240,000 years, the Cenozoic of 2,900,000 years, and the entire series of fossiliferous sedimentary rocks of 27,650,000 years. To this there is to be added the period in which all of the sediments were deposited between the basal crystalline Archean complex and the base of the Paleozoic. Notwithstanding the immense accumulation of mechanical sediments in this Algonkian time, with their great unconformities and the great differentiation of life at the beginning of Paleozoic time, I am not willing with our present information to assign a greater time period than that of the Paleozoic—or 17,500,000 years. Even this seems excessive. Adding to it the time period of the fossiliferous sedimentary rocks, the result is 45,150,000 years for post-Archean time. Of the duration of Archean or pre-Algonkian time, I have no estimate based on a study of Archean strata to offer. If we assume Haughton's estimate of 33 per cent. for the Azoic period and 67 per cent. for the sedimentary rocks, Archean time would be represented by the period of 22,250,000 years. In estimating for the Archean, Haughton included a large series of strata that are now placed in the Algonkian of the Proterozoic of the United States Geological Survey; and I think that his estimate is more than one-half too large; if so, ten million years would be a fair estimate, or rather conjecture, for Archean time.

Period.	Time Duration.
Cenozoic, including Pleistocene	2,900,000 years
Mesozoic	7,240,000 "
Paleozoic	17,500,000 "
Algonkian	17,500,000 "
Archean	10,000,000(?)"

It is easy to vary these results by assuming different values for area and rate of denudation, the rate of deposition of carbonate of lime, etc.; but there remains, after each attempt I have made that was based on any reliable facts of thickness, extent and character of strata, a result that does not pass below 25,000,000 to 30,000,000 years as a minimum and 60,000,000 to

70,000,000 years as a maximum for post-Archean Geologic time. I have not referred to the rate of development of life, as that is virtually controlled by conditions of environment.

In conclusion, geologic time is of great but not of indefinite duration. I believe that it can be measured by tens of millions, but not by single millions or hundreds of millions of years.

CHARLES D. WALCOTT.

ON THE ORIGIN OF THE PENNSYLVANIA ANTHRACITE.[1]

Long ago, H. D. Rogers showed that the coal regions of Pennsylvania are divided into rudely longitudinal basins or troughs. In passing over the state northwestwardly, one crosses first the Archean area at the southeast, with its patches of Newark or Triassic; then the Great Valley, extending almost unbroken from the Hudson river to Alabama, and showing only Cambrian and Silurian with occasional patches of Devonian and Lower Carboniferous. Crossing the irregular northerly or northwesterly boundary of the valley, he reaches what, for the purpose of this discussion, may be termed the Anthracite Strip, which extends to the Alleghanies; this contains the Cumberland coal field of West Virginia and Maryland, the Broad Top field of southern Pennsylvania, and, still further northeast, the Southern, Middle and Northern Anthracite fields. The Bituminous coal basins, of which Rogers recognized six, are beyond the Alleghanies; the first, between the Alleghanies and Laurel Hill, is well defined near the Maryland line, but becomes less so northward, though it can be traced without difficulty into New York; the second, with Chestnut Hill as its westerly boundary, is the Ligonier Valley, which like the last can be followed into New York; the third, wider than the second, is less defined at the west, as its boundary on that side is an anticline passing but a little way east from Pittsburgh and producing insignificant topographical effects; the most important portion of the basin, in this connection, is the first sub-basin, known as the Connellsville coke basin, which follows the westerly foot of Chestnut Hill. The remaining bituminous basins, including the rest of

[1] Abstract of a paper read before the Geological Society of America, August, 1893.

Pennsylvania, northwestern West Virginia and eastern Ohio may be regarded as one, their details being unimportant in so far as the present study is concerned.

The trend of the anticlinal and synclinal axes is not N. N. E. and S. S. W. throughout, for one of the great curves of the Appalachian system is within Pennsylvania; the axis of the First Bituminous basin, for example, follows an almost W. S. W. direction until, in Clearfield county, midway in the state, its course is changed to S. S. W.; any topographical map of Pennsylvania illustrates the condition.

Interesting variations in the rate of dip are shown along a line drawn from Pittsburgh, Pa., southeastwardly across the coal area to the Cumberland field in Maryland, the contrast between the terminal conditions being very great. At Pittsburgh, the rate seldom exceeds one degree; in the Connellsville sub-basin it varies from four or six degrees along the lower portion of the trough to somewhat more than ten degrees on the side of Chestnut Hill, the increase in rate thus far being quite regular. No further increase is found in crossing the second and first basins, the dip even on the easterly side of the Alleghanies rarely exceeding twelve degrees. But the extent of disturbance becomes markedly greater at once after the Anthracite Strip has been reached, for there dips of 20, 40, 70 and 80 degrees are seen.

The conditions observed along this line are not representative of those throughout the coal area, for in all the basins, even in those of the Anthracite Strip, the degree of disturbance eventually becomes less along the trend northwardly. The existence of the anthracite fields themselves is due to a remarkable decrease in violence of the disturbance, a dying away northward of anticlines, permitting formation of broad synclines, which in their turn act as do the canoe synclines of the bituminous areas, which, rising, send the lower formations into the air. Southwardly, the condition is markedly different; for though the extent of disturbance, except in the Anthracite Strip, decreases rapidly, the decrease is due to depression of anticlines and not,

as at the north, to the general elevation of the synclines and their passage into the New York plateau.

Analyses of coal samples, taken from the Pittsburgh bed in the several basins, show a progressive decrease in the proportion of volatile, combustible matter toward the east or southeast, a fact which early attracted the attention of H. D. Rogers, and which has possessed much interest for geologists ever since. Analyses made for the Second Pennsylvania Survey prove the same condition in the lower coals. Mr. Winslow's studies of the Arkansas coals show a similar tendency to decrease in the same direction; and Murchison discovered a like condition in the Donetz anthracite field of southern Russia.

H. D. Rogers,[1] in 1842, announced to the Association of American Geologists the law of gradation, as he understood it, which involves "a progressive increase in the proportion of the volatile matter, passing from a nearly total deficiency of it in the driest anthracites to an ample abundance in the richest caking coal." Finding, as he believed, that the volatile matter in the coal augments westwardly, precisely as the flexures diminish, he attributed the variation to the influence of steam and other intensely heated gases escaping through crevices necessarily produced during the permanent bending of the strata. Under such conditions, the coal throughout the eastern basins, the more disturbed, would discharge more or less of the volatile constituents during the violent earthquake action, whereas the more western beds, less disturbed, would be less debituminized.

J. J. Stevenson,[2] in 1877, showed that the variations in volatile exhibited by the Pittsburgh coal bed along the southeast and northwest line bear no relation whatever to increase or decrease of stratigraphical disturbance, and suggested that the variations are due to difference of conditions under which the coal was formed.

[1] ROGERS: Reps. of the 1st, 2d and 3rd meetings of the Association of American Geologists and Naturalists. 1843, pp. 470 et seq.

[2] STEVENSON: 2d Geol. Surv. of Penn., Rep. of Progress on the Fayette and Westmoreland Dist. Pt. I. pp. 61, et seq.

J. P. Lesley,[1] in 1879, offered some interesting suggestions. If the anthracite be metamorphosed bituminous coal, the change might be caused by exposure to comparatively high temperature at a great depth below the surface. As the temperature increases one degree Fahrenheit for each fifty feet, more or less, of descent, the coal under cover of a great thickness of rock could not fail to be deprived of its volatile matter. He compares the composition of coal from the highest available bed in western Pennsylvania with that from the lowest bed in the same region, and finds less volatile in that from the lower bed. As all of the Paleozoic rocks thicken eastwardly, there must have been a much greater pile of Coal Measures in the anthracite region than in the bituminous areas, though erosion has removed the proof. Necessarily then the coals of the anthracite region should show less volatile than do those of the bituminous area, where the pile of rocks was less thick.

Professor Lesley suggests also that if one desire to explain the origin of the anthracite by oxidation in preference to metamorphism, the conditions afford basis for such explanation, since in the anthracite region the rocks are not only broken and shattered by the folding, but they are made up largely of sand and gravel, so that the conditions are such as to favor percolation of water, evaporation, and consequently oxidation; whereas, in the undisturbed bituminous areas, clayey beds are in large proportion and lute down the buried coals so as to prevent percolation and the rest.

There is no possible room for doubt that bituminous coal can be converted into anthracite by heat. The Galisteo, Elk Mountain and other localities within the United States, the Hesse Cassel and New Zealand areas in foreign lands, prove beyond dispute that, under proper conditions, contact with molten rocks suffices for the conversion. But no question of such conversion is at issue here, for in Pennsylvania no dikes occur near enough to the anthracite areas, or large enough even if near enough, to

[1] LESLEY: In McCreath, 2d Geol. Surv. of Penn., 2d Rep. of Progress in the Laboratory, etc. 1879, pp. 153, et seq.

produce by contact the extensive tracts of anthracite still remaining in the state.

Professor Rogers's explanation seems to have been based throughout on a misunderstanding of the conditions. There is no good reason for supposing that the Appalachian Revolution was produced by violent disturbances such as those imagined by Professor Rogers; on the contrary, there appear to be the best of reasons for supposing the final folding to be but an acceleration of the process which had gone on, perhaps not continuously, from a very early period. The slowness of the process even at the close is suggested by the courses of the main waterways. The fundamental error, however, respects the relation of dip and volatile. The dip along the line selected by Professor Rogers, that from Pittsburgh to the Cumberland coal field in Maryland, does indeed show great changes, but as already stated they are not gradual. Let the condition be recalled. At Pittsburgh, the dip is from ½° to 1°; in the Coke basin, 30 miles away, it is from 4°–6° at the lower portion of the trough, to 10°–12° higher up the side of the anticline; in the Salisbury basin, 34 miles further, the dip is the same or less, there being practically no change in the interval from the Coke basin; and no further change is found until one has passed the Alleghanies and entered the Anthracite Strip, where a marvelous change is seen, for the dip is sometimes vertical. Now despite all this, the decrease in volatile, as shown by the Pittsburgh coal bed along this line, is almost regular; thus at Pittsburgh, the average analysis shows of volatile 40.7 per cent. (ash and water being ignored in the calculation); at Connellsville, 33.8, a decrease of 6.9 in 30 miles with an increase of dip from 1° to say 8°; at Salisbury, the volatile is only 23.3, a decrease in 34 miles of 10.5 with no change whatever in rate or type of folding; while in the Cumberland basin, about 15 miles further, the volatile is 18.8, a decrease of only 4.5, despite the complete change in type and remarkable increase in extent of disturbance; and this last field is within the anthracite strip itself, is in proper position, along the trend, to be the continuation of the Northern Anthracite field.

Professor Rogers's error in this matter prevented him from observing that the volatile decreases northwardly along the trend in the several basins even more notably than along the line chosen by him. The hardest anthracite is not in the Southern field, where the folding is most complicated, but in the Eastern Middle. The Southern Anthracite field shows all gradations from bituminous coal at its southern extremity to hard, dry anthracite at its northerly end.

Professor Lesley's suggestion that the Coal Measures attained to much greater thickness in the anthracite region than in the bituminous areas hardly accords with the facts as now known, many of them published since he offered his suggestions. It is altogether certain now that the lower three divisions of the Coal Measures in Pennsylvania, the Pottsville, the Lower Coal Group and the Lower Barren Group, do not show any variations which would justify one in basing a theory upon them; and it is much more than probable that the Upper Coal Group and the Permo-Carboniferous attain their greatest thickness in the north central portion of the Appalachian basin, and that they diminish in thickness westwardly, northwardly and eastwardly from southwestern Pennsylvania, as abundantly appears from the measurements made by I. C. White and by the writer in Pennsylvania, Ohio and West Virginia. In any event, the thickness of the mass in northeastern Pennsylvania was small in comparison with the thickness of the series in Virginia, West Virginia and Kentucky, on the southeastern edge of the Appalachian basin; yet in those states the coal shows no tendency to be anthracite; that of the Imboden coal bed of Virginia and Kentucky, almost at the base of the Lower Coal Group of Pennsylvania, is richly bituminous.

Nor does the theory that anthracite is bituminous coal converted by heat due to mechanical force, commend itself in this connection. The crushed and polished coal of the Broad Top field is bituminous, whereas the uncrushed coal of the Northern field in the same strip is anthracite. The Quinnimont coal, in the gently flexed New River district of West Virginia, has

practically the same amount of volatile as is found in the same coal near Pocahontas, Virginia, close to the great fault of Abbs valley.

But it is unnecessary to look to metamorphism for an explanation of the Pennsylvania anthracite; at best, metamorphism is an unsatisfactory explanation, because it is difficult to find evidence that metamorphosing agencies have been in operation there. One does not think of metamorphism when he finds in the coal of a given bed a variation of five or ten per cent. of volatile within short distances, or even when he finds, as in Sullivan county of Pennsylvania, anthracite in one bench and bituminous in another bench at the same opening.

As was shown long ago by Bischof and others, anthracite can be produced simply by continuation of the process whereby vegetable matter is converted into bituminous coal—by continued formation of carburetted hydrogen until the hydrogen has been removed. Professor Lesley's ingenious suggestion that this can go on more readily in the anthracite region than in the bituminous areas, because of the difference in composition and condition of the rocks, hardly suffices. If only the extremes of the series were to be accounted for, and if all were confined to the anthracite strip, it might be regarded as sufficient; but all gradations from rich caking coal to anthracite occur in the First bituminous basin, where the rocks are comparatively undisturbed and consist largely of argillaceous shale. Moreover, in a single colliery within the Southern Anthracite field, one bench of the Mammoth bed yields a more than semi-bituminous coal, while from another is obtained almost the driest of anthracite. But an equally serious objection is, that the coal must have been converted finally before complete entombment, so that the effect of the pressure would be to remove water and to solidify the coal. The hardening of the coal was complete in the Broad Top field before the Appalachian revolution occurred, for in the final folding the coal, as shown in some mines, was broken into lenticular and polished fragments precisely like those of the Utica shale within the disturbed valley east from the Anthracite Strip. The Lara-

mie coals on the western side of the great plains in New Mexico, Colorado and Wyoming can hardly have undergone any material change since the final burial; otherwise the strange variations in composition would be inexplicable, the difference in condition as to character of rocks and degree of disturbance being insufficient.

Twenty years ago the writer, while connected with the Ohio Survey, reached the conclusion that the marsh, from which sprang the several beds of the Upper Coal group, originated at the east; two years later he was led to assert that the coal beds were formed as fringes along the shore of the Appalachian basin. If this be the true doctrine, there should be found in northeastern Pennsylvania,

First. A vastly greater thickness of coal than in other portions of the basin.

Second. A greater advance in the conversion of vegetable matter into coal, owing to the longer period elapsing prior to entombment.

As to the first condition, there can be no doubt. A comparison of the several divisions of the Coal Measures as they appear in the several basins of the state illustrates it well; but such a comparison would be tedious here, and only the Lower Coal group of the Pennsylvania series is used (that lying between the Pottsville conglomerate below and the Mahoning sandstone above).

In the Anthracite Strip this group shows in the several fields, from south to north, as follows:

Cumberland Field, bituminous, - - -	13′
Broad Top Field, bituminous, - - -	14′–15
Southern Anthracite, bituminous to anthracite, -	18 –60′
Middle and Northern Anthracite, anthracite, -	40 –58

The thicknesses in the Bituminous basins are:

First, - - - - - -	21 –23′
Second, - - - - - - -	19 –22′
Fifth, - - - - -	8 6″–13′4″

The thicknesses, as given for the Anthracite Strip, are those

of coal exclusive of slate and other partings, but those for the Bituminous areas include the slates and other partings, so that the actual amount of coal is less than the figures indicate. It is sufficiently clear that the conditions favoring the accumulation of coal in beds continued longer without interruption in the anthracite region than they did elsewhere within the Appalachian basin; for the contrast is equally marked, when the anthracite region is compared with the Virginias or Kentucky further southwestward. The process of conversion also continued longer without interruption, as the chemical analyses show.[1] Thus, in the Anthracite Strip, one finds:

Cumberland Field (only the Pittsburgh),	4.47– 4.78	Coal, 13′
Broad Top Field, - - -	3.26– 4.64	Coal, 14′
Southern Anthracite Field,		
Southern prong, - -	4.36–12.40	Coal, 18′–30′
Main Field, - - -	11.64–23.27	Coal, 30′–60′
Western Middle Field, -	19.87–24	Coal, 40′–58′
Eastern Middle Field, - -	25.53–30.35	Coal, 52′–53′
Northern Field, - -	19.37–19.92	Coal, 44′–53′

The anthracite analyses are commercial, samples chosen from carload lots. Very much higher ratios are obtained by sampling single benches.

The First and Second Bituminous basins show a similar change along the line of trend, the amount of volatile decreasing northwardly as one approaches the old shore line.[2] Thus, in the First, the Clarion coal bed shows from 2.94 to 4.84 near the Maryland line, but from 7.07 to 10.28 in Sullivan county, where is its last exposure at the north. In the Second basin, the Upper Freeport coal shows 2.26 to 2.85 near the Maryland border, but 3.96 to 4.48 at the last northerly exposure, in Lycoming county. The variations in the Third and other basins are less, as one

[1] The figures here given are the ratios between the Fixed Carbon and the Volatile Combustible, the ash and water being ignored; the more volatile, the smaller the ratio.

[2] Some curious variations, apparently contradictory of the statement here made, occur in the analyses. These will be discussed and their interest shown by the writer in a review of theories respecting the origin of coal beds, which is now in course of preparation.

should expect, for according to the supposition, the conditions at that distance from the old shore line should vary little anywhere.

So one finds,

First. A decided increase in thickness of coal eastward, or better, northeastward toward the anthracite region, and a less marked increase northward in the Bituminous basins.

Second. A decided decrease in volatile in the direction of increased thickness of coal, the decrease being comparatively gradual until near the anthracite fields.

Third. That this decrease is gradual even in the Anthracite Strip from the Cumberland Field to the semi-bituminous coals of the Southern Anthracite field, where the rapid increase in thickness is accompanied by a rapid decrease in the volatile.

When, in 1877, the writer called the attention of his colleagues on the Pennsylvania Survey to the fact that the decrease in volatile is wholly without relation to increase or decrease of disturbance in the strata, he suggested that the variation was due to difference in conditions under which the coal had been formed in the several localities discussed—a sufficiently comprehensive hypothesis, but yielding in this respect to some others of later date. Now, however, there seems to be no good reason for any such suggestion; all that was needed was longer exposure to the process whereby ordinary bituminous coal was formed. In origin, the anthracite coal of Pennsylvania differs in no wise from the bituminous coal of other parts of the Appalachian basin; but because the great marsh, from which sprang the many beds, originated in the northeastern corner of the basin and extended thence again and again on the advancing deltas formed by streams descending from the Appalachian highlands, the time during which the successive portions of the marsh would be exposed would be less and less as the distance from the northeastern and northern border of the basin increased, so that the extent of chemical change would decrease as the distance increased. It is, therefore, to be expected that in the northeastern corner, where the deltas were formed quickly after subsidence was checked, and

beyond which they advanced slowly, as shown by changing type of rocks, the chemical change should have been almost complete, especially in the eastern Middle and the eastern extremity of the Southern field, which occupy that part of the area in which the coal marsh, in almost every instance, appears to have thrust itself first upon the advancing delta.

It is quite possible that when detailed study of the anthracite areas in Arkansas and Russia have been made, the same explanation may be found applicable there also, and that the anthracite will be found near the old shore line, whence the marsh advanced as new land was formed. JOHN J. STEVENSON.

THE BASIC MASSIVE ROCKS OF THE LAKE SUPERIOR REGION.

III. THE GREAT GABBRO MASS OF NORTH-EASTERN MINNESOTA.[1]

A. Introduction.

As HAS already been stated in an earlier paper,[2] the writer purposes, as time and opportunity permit, to discuss the petrographical and stratigraphical relationships of the basic rocks that constitute such an important element in the geology of the country bordering Lake Superior. In the series of papers, of which this is the first, the petrographical characteristics of the various types of these rocks will be described, and the views held by previous workers with respect to their geological relationships will be outlined. Thus, it is hoped, a foundation will be laid for a new and more thorough investigation of the field relations of these rocks than has heretofore been possible. As the case now stands, several of the geologists who have investigated the eruptive rocks of this region have erred in confusing types of entirely different origins, and have thereby introduced into the literature errors of observation that have rendered a clear understanding of the Lake Superior geology almost impossible.

When practicable the laboratory and field study of rocks should proceed together, each aiding the other in solving the knotty problems that so often arise in their progress. The laboratory study of the eruptives in the region under consideration has been almost entirely neglected, and consequently the field problems arising in connection with them have largely remained unsolved. When the peculiarities of these rocks—their composition and structure—become known, much light will be thrown upon their nature, and it will then be time to again review their field relations, when it is believed that many

[1] This Journal, Vol. I., pp. 433 and 587.

[2] This Journal, Vol. I., p. 435.

of the difficulties now surrounding them will disappear. At present the main results reached by the field-geologists who have busied themselves with the rocks under discussion will be referred to. They must pass unchallenged except in the few cases where the microscopic evidence is directly at variance with them; and when there is no field evidence directly substantiating them. At some time in the near future it is hoped that an opportunity will offer itself for a more detailed study of the rocks in the field. Then it will be proper to criticise the conclusions arrived at by previous workers, and to suggest new views as to the position and relation of the eruptives with respect to the rocks with which they are associated.

B. The Position of the Gabbro.

The great gabbro mass which is the subject of this paper has been placed by Irving in the Keweenawan group, the separation of which from the underlying Huronian slates and quartzites and the overlying Cambrian sandstone, is due principally to the investigations of Brooks, Pumpelly, Irving and Chamberlin. The history of the discussion which has led to the recognition of the great Keweenawan series it will not be necessary to outline, as it is well given in the essays, whose authors have been named.[1]

The only detailed description of the series as a whole has been given us by Irving,[2] who makes it "include only the suc-

[1] It should be stated here that although the individuality of the copper-bearing series of rocks is recognized by nearly all geologists who have worked in the Lake Superior region, several have declined to regard it as a distinct series, equivalent to the Huronian or the Cambrian. These geologists prefer to look upon it as belonging with the latter group as its lower member. Dr. Wadsworth has long held this view, and Prof. N. H. Winchell (8th Ann. Rept. Geol. and Nat. Hist. Survey of Minn., p. 22; 17th ibid., pp. 54-55) in one of his most recent reports sums up the work of the Minnesota Survey in this direction in the statement that the Keweenawan series is closely linked with "the great gabbro flow," to which reference will be made hereafter, and that both are members of the Potsdam. In a later report (20th Ann. Rept. Geol. and Nat. Hist. Survey of Minn., p. 3) the same writer discusses the age of the gabbro and concludes that it is much older than the Potsdam, but he does not assert positively that the Keeweenawan beds overlying it are pre-Cambrian.

[2] The Copper-Bearing Rocks of Lake Superior, R. D. IRVING: Monograph V., U. S. Geol. Survey, Washington, 1883.

cession of interbedded 'traps,' amygdaloids, felsitic porphyries, porphyry-conglomerates, and sandstones, and the conformably overlying thick sandstones, as typically developed in the region of Keweenaw Point and Portage Lake on the south shore of Lake Superior."[1]

Although no distinct line of division between them can be pointed out, the beds of the series naturally fall into an upper division made up wholly of detrital material, principally shales and red sandstones, and a lower division consisting chiefly of a succession of basic flows, layers of conglomerate and sandstone and quite a large proportion of flows of acid eruptive rocks. The thickness of the upper division is estimated at 15,000 feet at its greatest, and that of the lower division at from 22,000 to 24,000 feet.

The recent discovery that the central part of the Keweenawan is underlain unconformably by a great mass of anorthosite, which along the middle portion of the Minnesota coast comes to the surface in many places, suggests to Lawson[2] that the maximum thickness of the lower Keweenawan beds at this place must be much less than Irving's estimate. His own figures are only about one-tenth those of Irving. VanHise[3] in a review of Lawson's article takes exception to the author's small estimate, and prefers to accept Irving's figures, until these are proven inaccurate by careful detailed investigation of the problem in the field.

Since it is only in the lower division that eruptive rocks occur, our attention will be confined entirely to this. It is not possible to determine positively for the entire series the actual succession of the subordinate members belonging in it, for this, in an eruptive series, may vary in different areas, but Irving believes that the following "broad horizons" may be recognized: (1) a succession of heavily bedded coarse-grained olivine and orthoclase gabbros, forming the base of the series; (2) a series of olivine diabases and diabase-porphyrites, occurring at the lower hori-

[1] l. c., p. 24.

[2] Geol. and Nat. Hist. Survey of Minn., Bull. No. 8, p. 21.

[3] Jour. of Geology, Vol. I., p. 312.

zons, together with acid eruptives of all kinds common to the group, as quartz-porphyries, quartzless-porphyries, and fine-grained red granites; (3) olivine-free diabases and other basic rocks with amygdaloidal upper and lower surfaces; and (4) detrital beds, chiefly porphyry conglomerates and sandstones, rare in the lower third of the series, but increasing in thickness and frequency towards the top. These various subordinate divisions have been separated into smaller sub-divisions, and their sequence, where possible, has been carefully detailed, but since a discussion of this classification is not necessary to our present purpose it need not be entered upon.

The lowest of the divisions of rocks belonging in Irving's Keweenawan has been said to consist of a succession of heavily bedded coarse-grained olivine and orthoclase gabbros. The best exhibition of these gabbros is found in north-eastern Minnesota, where the area underlain by them occupies about 2100 miles of the surface of the state, extending from the east line of Range 1, E., to about the middle of Range 15, W. The general shape of the area is crescentic with the concave side turned toward Lake Superior and its convex side facing the north-west. In its widest part the crescent measures about twenty-two miles from south-east to north-west. The chord connecting its two horns is about 125 miles in length. The eastern extremity forms a narrow point about three miles north-west of Greenwood Lake, from which point the area extends westward, widening gradually until it reaches its broadest expanse, and then gradually contracting until it finally abuts against the north shore of St. Louis Bay west of Duluth, where it appears as a band forming the shore line for ten or twelve miles, beginning in the western portion of the city of Duluth and ending four miles east of Fond du Lac.

A second[1] area of basal gabbro is in the Bad River region in Wisconsin. Here the rock forms a narrow belt about forty-eight miles in length and from two to five miles in width, stretching from the Gogogashugun river south-westward to near Numakagon lake, in T. 43 N., R. 6 W., Wis.

[1] Cf. pl. XXII., Copper-Bearing Rocks.

It was not until a few years since that an attempt was made to discover the true relations of these gabbros to the surrounding rocks. In his Copper-Bearing Rocks (p. 266) Prof. Irving places them at the base of the Keweenawan group, at the same time stating that "There is no definite evidence of unconformity between the gabbros and the slates of the Saint Louis River," regarded as Animikie. In a later paper the same writer[1] refers to a coarse-grained, stratiform olivine-gabbro at the base of the Keweenawan.

Though nowhere so stated, the olivine-gabbros had by this time been separated by the author from the overlying "orthoclase gabbros," and had been placed by him at the very base of the Keweenawan group, with the orthoclase-gabbros immediately above them. In his article[2] on the classification of the early Cambrian and pre-Cambrian formations, we have this description of the position and nature of this great mass of rocks, ". . . . We find at the base of the series [Keweenawan] an immense development of stratiform, fresh and often exceedingly coarse olivine-gabbro, the individual layers of which, notwithstanding their complete crystallization, very coarse grain, and lack of amygdaloidal or dense upper surfaces, seem evidently to have formed great flows at the surface of the region as it stood at the time of their extrusion."

No more explicit statements of his views concerning this basal gabbro appear in any of Irving's writings. A reference to the geological map of north-eastern Minnesota accompanying the paper last referred to, will, however, show that at this time (1886) he believed the basal gabbro in Minnesota to rest unconformably upon the Animikie, since the former is represented as cutting transversely belts of St. Louis slates, the Mesabi granite and schists of the Archean, and the eastern area of Animikie slates along the boundary line between Minnesota and Canada, which slates here strike nearly east and west.

Although in his maps the "gabbro flow" is represented as

[1] Am. Jour. Sci., 3d ser., vol. 34, 1887, pp. 204, 249.

[2] Seventh Ann. Rept. U. S. Geol. Survey, 1888, p. 419.

belonging with the Keweenawan rocks, the Wisconsin mass was nevertheless recognized by Irving as presenting "the appearance of a certain sort of unconformity with the overlying beds. These gabbros, which lie immediately upon the Huronian slates, form a belt which tapers out rapidly at both ends, and seems to lie right in the course of the diabase belts to the east and west, since these belts, both westward toward Lake Numakagon, and eastward toward the Montreal river, lie directly against the older rocks, without any of the coarse gabbro intervening." . . . "The great extent of coarse gabbro in Minnesota seems to sustain somewhat the same relations to more regularly bedded portions of the series." [1]

The only other descriptions of this great gabbro mass are to be found in the reports of the Minnesota survey. In the report for 1887 Prof. N. H. Winchell[2] details a few of his observations on the "great gabbro flood," and surmises that the "flow" did not escape through a single fissure. The structure of the rock is reported as roughly columnar, with sometimes apparent indications "of the existence of imbricating layers having a gentle dip, as if the fluid rock had swept over the country in successive tides. . . . In texture the gabbro is characteristically coarse. Sometimes some of the constituent minerals are half an inch in diameter. From this they graduate down to an extreme degree of fineness."

From the macroscopic descriptions of other varieties of the rock that follow it is evident that the writer is not dealing exclusively with specimens taken from the great "gabbro flood" at the base of the Keweenawan, for, as the sequel will show, this is composed of a rock which, in its unaltered state, possesses a remarkably uniform texture, and is so well characterized that any departure from it is presumptive evidence that the rock exhibiting the variation belongs not in the "basal flow," but in some one of the numerous smaller beds interstratified with the Animi-

[1] Copper-Bearing Rocks, p. 155.

[2] Geol. and Nat. Hist. Survey of Minnesota, 16th Ann. Rept. for 1887. St. Paul, 1888, pp. 360-362.

kie and the Keweenawan strata at various horizons, or in some one of the many dykes cutting these.

In the report[1] of the following year, upon referring to the position of the gabbro with respect to the other formations, Prof. Winchell says . . . "In general the gabbro lies on the Animikie (Taconic) in Minnesota." At Chub (Akeley) lake, however, it seems to be underlain by a bed of quartzite, regarded as a lower member of the copper-bearing formation of the Potsdam (Keweenawan of Irving and Chamberlin) in the seventeenth report, but looked upon as Animikie and denominated the Pewabic quartzite in the sixteenth report,[2] and described under the field name "muscovado" in earlier reports.

In a more recent discussion[3] as to the age of the gabbro, Prof. Winchell briefly summarizes his previous views on the subject, and concludes that the supposed quartzite underlying the gabbro belongs near the bottom of the Animikie, and since the eruptive rock is so closely associated with the fragmental one, that the former must be of nearly the same age as the latter.[4]

This conclusion is based on the supposition that the rocks immediately underlying the gabbro are fragmental quartzites that have been altered by the eruptive for miles even from its contact with them.[5] But this is probably not always the case. As the writer[6] has shown in another place, some of the so-called quartzites are very basic crystalline aggregates of pyroxene and olivine, and others are granulitic phases of the overlying gabbro. Since they are portions of the gabbro they are of the same age as this, and are not available as stratigraphical data for use in determining the time relations of the great "flow" with respect

[1] 17th Ann. Rept. for 1888. St. Paul, 1891, p. 52.

[2] 16th Ann. Rept., pp. 82-87.

[3] The Iron Ores of Minnesota. Bull. Minn. Geol. Survey, No. 6, 1891, p. 125.

[4] Cf. also: 20th Ann. Report, p. 2.

[5] H. V. WINCHELL: Ib. p. 127.

[6] BAYLEY W. S.: Notes on the Petrography and Geology of the Akeley Lake Region in Northeastern Minnesota. 19th Ann. Rept. Minn. Survey. Minneapolis, 1892, p. 193 et seq.

to the Animikie and the Keweenawan rocks. Some of the rocks, called by Winchell Pewabic quartzite, are probably true Animikie fragmentals, or metamorphosed phases of these, but even in this case there is no proof that the gabbro immediately succeeds them in point of age. The evidence would simply indicate that the eruptive is younger than the Animikie. It would not fix its age more definitely. The observations of Winchell would thus seem to lead to the same conclusion as that reached by Irving in so far as the latter supposed the gabbro to be post-Huronian.

Upon returning again to the problem as to the age of the gabbro Winchell [1] attempts to fix this more definitely by assuming the identity of this rock with the anorthosite, which is shown by Lawson to be older than the bedded Keweenawan. But it is impossible at present to assert with any degree of certainty, that the two rocks are the same (although VanHise holds with Winchell that their equivalency is possible), for the one has not been traced into the other, nor has the upper limit of the gabbro been carefully studied. This great mass may be much older than the lowermost beds of the Keweenawan series, but as yet there has been cited no proof in favor of the view.

So far as the little evidence at hand enables us to judge, the gabbro whose petrographical characteristics are discussed in this article, forms a great mass of enormous extent above the Animikie but below the interbedded flows and fragmentals of the Keweenawan series in Minnesota. There are obscure indications that the mass is a great layer composed of successive flows that followed one another so rapidly as to give no opportunity for the action of erosion processes or for deposition between them. If this be so the lack of more apparent bedding is doubtless due to the great thickness of the individual beds, as is also their coarse grain. There are some things about the mass, however, that suggest another origin for it. "The great coarseness of grain, the perfection of the crystallization, the abrupt termination of the belts, the complete want of structure, and the presence of intersecting areas of crystalline granitoid rocks — all suggest the

[1] Bull. No. 8. Geol. and Nat. Hist. Survey of Minn. p. xviii.

possibility that we have here to do with masses which have solidified at great depths. They certainly cannot, however, be regarded as intrusive in the ordinary sense of the word; so that, unless we regard them as great outflows, we should be forced to look upon them as the now solidified reservoirs from which the ordinary Keweenawan flows have come."[1]

C. Petrographical Description of the Normal Phase of the Gabbro.

Up to the present time there has appeared no general petrographic description of the great gabbro supposed to be at the base of the Keweenawan, although both Irving and Wadsworth have given detailed descriptions of hand specimens taken from it. The former writer,[2] in his monograph on the copper-bearing rocks, refers to the great mass at Duluth as consisting principally of a coarse orthoclase gabbro, but including some orthoclase-free gabbro. The rock is "massive and irregularly jointed, making great ledges facing in different directions, and furnishing bare rounded summits to the hills which it composes.

The prevalent type of the gabbro . . . is of a light gray color, and very coarse-grained, single feldspar crystals sometimes reaching even an inch or two in length. The augitic ingredient is plainly in greatly subordinate quantity, and often on a fresh surface its presence cannot be detected at all. On exposed surfaces, however, the weathering generally brings it out, and then it can be plainly seen to fill the spaces between the feldspars. Titaniferous magnetite is also often perceptible to the naked eye in large particles.

Less commonly the grain is finer and the color darker, the augitic ingredient at the same time becoming more plentiful. In the thin section the predominant feldspar is seen to be a plagioclase belonging near the oligoclase end of the series. There appears also to be a younger feldspar present, which has the character of orthoclase and fills corners between the plagioclase crystals, around whose contours it moulds itself sharply. Streng and

[1] Copper-Bearing Rocks, p. 144.

[2] Copper-Bearing Rocks, Mon. V., U. S. Geol. Survey, p. 266 and 269.

Kloos[1] found 1.61 per cent of potash in the rock, which they very properly regarded as belonging to orthoclase. The spaces between the feldspars are filled with a diallage which is always more or less altered to greenish uralite. The alteration in many sections is carried beyond uralite to chlorite. The magnetite is very large, abundant and titaniferous. Apatites of large size are found in all sections. Biotite is not an uncommon accessory. Olivine is absent from all sections."

It is very evident that the writer is not describing by these words the rock of the great 'flow' as he defined it in his later papers, but that he is dealing exclusively with the orthoclase gabbros, which were afterwards separated from the underlying mass and given a position just above this.[2]

The only specimen of the true basal gabbro examined by Irving[3] came from the Cloquet river, in Sec. 34, T. 53 N., R. 14 W. in Minnesota. This he characterizes as "A very fresh olivine-gabbro. It is light gray in color, very coarse grained, and [is] composed chiefly of very fresh plagioclase (anorthite). Quite fresh diallage fills in the space between the feldspars. A few large fresh olivines occur here and there in the section. Titaniferous magnetite is abundant, and large sized, and biotite occurs in a few small scales."

Dr. Wadsworth[4] made no attempt to describe the general features of this great mass of rock. His descriptions are of hand specimens furnished him for examination by the officers of the Minnesota survey. Among them were several representatives of the "basal flow,"[5] but these were not studied with reference to each other, except in regard to their alterations.

[1] Neues Jahrb. f. Min., etc., 1877, p. 113.

[2] See ante, p. 692.

[3] Copper-Bearing Rocks, p. 272, also p. 46.

[4] Geol. and Nat. Hist. Survey of Minnesota. Bull. No. 2.

[5] The specimens described by Dr. Wadsworth that are thought to belong to the basal gabbro are the following: No. 696, p. 69; 706 and 702, p. 70; 773 and 713, p. 71; 699, 769 and 701, p. 72; 689 and 721, p. 75; 780, p. 85; 707, p. 87; 693, p. 88; 694, 704 and 703, p. 89; 787, p. 90; 715, 692 and 777, p. 91; 691, p. 92; 700, 714 and 698, p. 93; 705, p. 94; 514 and 513, p. 95; 697 and 776, p. 96; and 781, p. 97.

It has already been intimated that the normal rock of the great gabbro is so uniform in its general character that, after studying carefully one of its hand specimens, others might easily be identified among a collection of specimens of the basic rocks of the Lake Superior region, without much danger of error. Its description, therefore, is quite a simple matter. In its macroscopic aspect the normal rock is a medium to coarse-grained, gray, granular aggregate of a very lustrous plagioclase and a black augite. The plagioclase is usually more abundant than the darker mineral; its dimensions are larger, and its contours more frequently approximate to those of crystals. It is of a light gray color and has a glassy lustre on fresh fractures, while on weathered surfaces it is white and opaque. Twinning striations are visible on nearly every grain. The augite on the contrary is jet black. Its cleavage faces are rather small, and its contours never approach those of crystals; they are occasionally triangular or wedge-shaped when they have any definite form, but are usually very irregular in outline. In some of the coarse-grained varieties of the rock there is a rudely lamellar arrangement of both the augite and the feldspar, so that the mass possesses a platy structure. With this exception the gabbro has the typical granitic texture, and is thus easily distinguished from all the other so-called flow gabbros of northeastern Minnesota and the region bordering on Lake Superior in which is more or less perfectly developed the diabasic texture.

The principal varietal differences noted in the rock are due solely to the proportions of feldspar, augite and olivine present in it. When the pyroxene is in moderate quantity the appearance of the specimen is as indicated above. Sometimes the feldspar is largely in excess, and pyroxene has almost entirely disappeared. Now the rock has a lighter gray color, and the bright shining black particles are lacking. Again olivine is the principal component when the tint of the rock becomes dark green. The structure in all cases, however, remains the same. The varieties are merely local phases of the predominant rock for on all sides they grade into one another by insensible transitions. The

density of the varieties depends of course upon their composition; the larger the proportion of feldspar present the lower the specific gravity. Of the three specimens whose densities were determined, one (10440) was found to have a specific gravity of 2.8061, another (8786) of 2.9475, and the third (8589) of 3.0636.

The sections of nearly all specimens taken from the interior of the gabbro area, or from points at some little distance from its northern edge are similar, in that they represent a very fresh rock, whose structure is monotonous and whose composition is quite simple. All contain magnetite, olivine, pyroxene and plagioclase as primary constituents, and many have in addition as secondary components, biotite, chlorite and quartz. The proportions of secondary products present are never sufficiently large to affect the characteristics of the rock as a whole, though they be abundant enough to change materially its appearance in thin section. The usual succession in the formation of the primary minerals is as indicated, and in this respect does the gabbro of the mass under discussion differ most essentially from the other "gabbros" of the same and neighboring regions, for in all of the latter rocks studied the pyroxene is younger than the plagioclase.

The feldspar is the most abundant of the essential components, sometimes constituting, as it does, almost the entire section. It is nearly always in large grains, whose contours are very irregular in shape, and only very rarely resemble those of the lath-shaped grains of diabasic plagioclase. The mineral is quite fresh and is devoid of secondary inclusions, other than a few flakes of kaolin and small flecks of some chloritic substance. The characteristic acicular inclusions of gabbroitic feldspar are sometimes absent from the plagioclase of the Minnesota rock, but more frequently they are present in the usual forms. Small areas of augite and little grains of biotite and magnetite are also enclosed in the feldspar, and dust-like particles are scattered everywhere throughout the grain. The inclusion of augite within the plagioclase would seem to show that the latter mineral is undoubtedly younger than the former; but certain triangular areas of pyroxene between grains of plagioclase would point to

the opposite conclusion. The amount of plagioclase in all portions of the gabbro mass is so great that it must have occupied a long period in its separation. It is probable that the augite began to separate from the magma that yielded the rock some time before the plagioclase, but that after the feldspar began to crystallize the two minerals grew side by side until all the pyroxenic material of the magma had been extracted from it, when the feldspar continued its growth unaccompanied by the formation of pyroxene. Thus some of the plagioclase is older than some of the augite, though the greater part is younger than the great mass of this mineral.

All the plagioclase grains are traversed by broad twinning lamellæ, the maximum extinction on each side of whose composition plane is about 35°. In order to determine accurately the nature of this plagioclase, the three specimens whose densities are given, were powdered and their feldspars separated by the Thoulet solution. Most of the mineral was precipitated when the density of the solution was between 2.674 and 2.728, the limits in the different cases being as follows: in specimen 8786 between 2.700 and 2.728; in 8589 between 2.700 and 2.711, and in 10440 between 2.674 and 2.712. As a small amount of the plagioclase in each specimen was more or less altered, the average of the above figures may be taken as representing the average density of the plagioclase in the gabbro. The method is justified in the fact that the optical properties of the powder in all cases was exactly the same, and that its precipitation was not in steps or stages, but was continuous between the limits mentioned. The mean density of the feldspar separated from the three rocks was thus 2.701, which indicates a very basic labradorite. In the feldspar of a specimen of the gabbro from the Cloquet river Irving[1] reports 52.40 per cent. of SiO_2, while for the most acid member of the bytownite series Tschermak[2] calculates 49.1 per cent. of SiO_2. The largest quantities of the powder in the above three cases fell respectively at 2.700, 2.711 and 2.712.

[1] Copper-Bearing Rocks, p. 439.

[2] Lehrb. d. Mineralogie, 2te Aufl. 1885, p. 439.

There can thus be no doubt that the feldspar throughout the entire mass of the rock is practically of the same character, since the three specimens tested were taken from three widely separated portions of the gabbro area, and each represents a distinct type of the rock. No. 8786 is very rich in olivine, No. 8589 contains much augite and a large quantity of brown biotite, while No. 10440 is very rich in feldspar and quite poor in pyroxene.

An analysis of the feldspar separated from No. 8786, and partial analyses of the plagioclase from the other rocks were made by Dr. W. H. Hillebrand. They are as follows:

	8786	8589	10440a	10440b
SiO_2	51.89	52.18	47.59	46.92
Al_2O_3	29.68	29.20	30.97	31.51
Fe_2O_3	.32	1.11	1.55*	1.29*
FeO	.37			
CaO	12.62	11.18		
MgO	.38			
K_2O	.50			
Na_2O	3.87			
H_2O (100°)	.07			
H_2O (above 100°)	.39			
Total	100.09			
Sp. Gr.	2.700	2.711	2.712	2.674

The figures under 8786 and 8589 correspond very closely with those of a basic labradorite. Those under 10440a and 10440b are abnormal, in that they indicate that the more basic portion of the feldspar in this rock has a lower specific gravity than the more acid one. The alumina in the four cases, however, corresponds quite well with the proportion of this oxide in basic labradorites. In Ab_1An_3, which Tschermak makes the dividing line between labradorite and bytownite, the percentage of alumina present is 32.8 per cent. Since the rock specimens from which these feldspars were separated represent the only phases of the gabbro that have retained the normal gabbro characteristics, it is probable that the feldspars themselves represent the variations within whose limits all of the feldspar in the great mass of the rock may be found. A comparison of this plagioclase with that of the very coarse diabase from the boss-like dike forming Pigeon

* All iron determined as Fe_2O_3.

Point, show it to be a little more acid than the latter, though not enough so as to cause it to be placed in a position in the plagioclase scale far removed from that of the feldspar of the diabase[1]. The corresponding figures for the two plagioclases are:

	SiO_2	Al_2O_3	Fe_2O_3 FeO	CaO	Na_2O
Gabbro	51.89	29.68	.69	12.62	3.87
Diabase	53.75	30.39	1.26	10.84	3.76

The augite is generally older than the plagioclase, although the latter mineral seems sometimes to mould the contours of the former one. The pyroxene occurs either in the interstices between the labradorite grains, or as narrow rims around the olivine, forming a mantle that surrounds these and separates them from the feldspar (see Fig. 1).[2] The mineral is very light colored, sometimes being almost colorless, but it is usually tinged

FIG. 1. Section of the olivine-gabbro, exhibiting the tendency of the pyroxene to include olivine grains. Section 1103. × 20.

with pink. It is moreover possessed of a diallagic parting, accentuated by dark decomposition products, the most abundant of which are tiny, irregular black and brown dots. These are scattered everywhere throughout the pyroxene, but are accumulated most thickly in the neighborhood of the cleavage lines. In some of the pyroxene pieces are the peculiar platy inclusions

[1] Bull. U. S. Geol. Survey, No. 109.

[2] Cf. M. E. WADSWORTH, Bull. No. 2, Geol. and Nat. Hist. Survey of Minn., Pl. III. Fig. 1. In this figure the author pictures a pyroxene and olivine bearing the same relation to each other as the diallage and olivine shown in Fig. 1 of this paper.

characteristic of gabbro diallage. These are often arranged in straight lines crossing the parting planes. They are frequently so crowded that the line of inclusions appears as a dark bar crossing the diallage at various inclinations to the cleavage, as in the most notable case (No. 8786), where the direction of the bar cuts the prismatic cleavage at 21° and on the same side of it as the extinction, which is 37° (see Fig. 2). Under polarized light the diallage appears as though polysynthetically twinned. The lamellæ holding the inclusions polarize with a slightly different

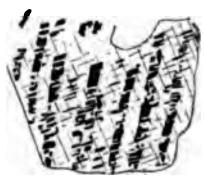


FIG. 2. Inclusions in Augite. Section 8786. × ca. 18.

color from that of the inclusion-free lamellæ. Moreover, the material in the immediate vicinity of the several inclusions seems to be more changed from its original condition than portions of the same lamellæ at a greater distance from them. This would indicate that the inclusions have absorbed some of the material of the pyroxene in their growth, and consequently that they are not original inclusions, as are those found by Williams[1] in the Cortlandt peridotites and norites, but are secondary like those discovered by Judd[2] in the peridotites and gabbros of the Western Islands of Scotland.

Under high powers a second cleavage can be detected as a series of fine lines perpendicular to the prismatic cleavage, in sections parallel to the vertical axis. Along these cleavage lines are disposed the inclusions with their long axes so arranged in the direction of the lines as to suggest that the latter were planes of easy solution—that the decomposition of the diallage first took place along them, and then attacked the pyroxene on both sides.

[1] Am. Jour. Sci., 3rd ser., vol. 31, 1886, p. 33; and vol. 33, 1887, p. 141.

[2] Quart. Jour. Geol. Soc., London, vol. 41, 1885, p. 354.

The only other alteration noticed in the diallage is along its edges, where brown and green hornblendes are developed, and in one case where the pyroxene is replaced in part by rosettes of chlorite that polarize in bright blue tints. The very deep pink color of some of the diallage plates may be due to incipient alteration, as along with the change in color there is produced a finely fibrous structure. The writer has searched earnestly for indications of enstatite[1] in the rock under consideration, but has failed to discover any, though strongly pleochroic hypersthene is present in large quantity in certain of its phases to be mentioned later. In one or two specimens of the normal gabbro there is also a little hypersthene, but it is not finely fibrous, and it occurs as very compact plates side by side with equally compact and very fresh plates of diallage.

Much of the pyroxene, as has been said, is in the interstices between the plagioclase and therefore is probably younger than this constituent. It is, however, not in the ophitic areas characteristic of diabasic pyroxene, but is usually in narrow stringers between the feldspar grains, and between these and the olivine. In some sections every grain of olivine is thus separated from plagioclase (Fig. 1), while in other sections, where this is not the case, the diallage is in too small quantity to serve this purpose. Narrow rims of this mineral also exist around magnetite and biotite, and they occur between these two minerals and olivine and a fibrous growth that surrounds them, especially the olivine, in a manner resembling a reaction rim.

Attempts to isolate the diallage for analysis were not successful, as it was found impracticable to free its powder from hypersthene and the brown earthy decomposition products of olivine.

The last mentioned mineral is usually quite fresh, and in large quantity, though in a few specimens it is represented by only an occasional grain in the thin section. Since it was one of the first separations from the magma yielding the rock, it is always present in more or less well defined idiomorphic grains. These are

[1] Cf. M. E. WADSWORTH: Nos. 787 and 692, pp. 90 and 91. Bull. No. 2 Minn. Geol. Survey.

transparent and almost colorless. In thick pieces a yellowish green tinge may be noticed, but in thin slices no recognizable tint may be detected. The inclusions are opaque dendritic particles, spongy magnetite, and secondary products, among which may be mentioned yellowish serpentine, chlorite, and opaque and yellowish-brown earthy substances. These may occasionally entirely replace the original mineral, but more frequently they occur only in the cleavage and other cracks in the fresh olivine, or along its edges.

In most cases the olivine is so fresh that it was thought worth while to have an analysis of it. This has been made by Mr. Hillebrand, who had furnished him a powder consisting of beautifully fresh olivine intermingled with a little diallage, the mixture having been separated from rock No. 8589 by means of methylene iodide. The olivine was isolated by digestion with hydrochloric acid, and the solution obtained was analyzed with this result:

SiO_2	TiO_2	Al_2O_3	Cr_2O_3	FeO	MnO	CoO	NiO	CaO	MgO	H_2O	Total.
35.58	1.22	.92	tr.	33.91	.35	.20	?	.90	26.86	.31	100.25

The olivine is thus a hyalosiderite with Mg : Fe about 1½ : 1. The small quantities of manganese and cobalt present in it are of interest from the point of view of Sandberger,[1] as affording another indication that olivine is frequently that constituent of a rock which is the source of the material for ore segregations. In the present instance they are of little significance, however, since so far as known the only ores occurring within the large areas covered by the basal gabbro are magnetite and ilmenite. At Copper Lake, in Secs. 9 and 10, T. 64 N., R. 4 W., weathered masses of the gabbro are stained with a green coating of malachite, and the same[2] staining has been noticed at the contact of the Pigeon Point gabbro with a red granophyric rock, where it has resulted from the alteration of chalcopyrite, but in neither case is the copper compound in sufficient quantity to constitute an ore.

[1] Cf. J. F. KEMP: A Brief Review of the Literature of Ore Deposits. School of Mines Quarterly, XI., No. 4, p. 366.

[2] Bull. U. S. Geol. Survey, No. 109.

The relation existing between the olivine and the diallage is the most interesting of the phenomena presented by the rock. It has already been stated that but very few olivine-grains are in direct contact with feldspar. Around nearly all are narrow rims of pyroxene. At first glance these appear to be a sort of reaction rim between the two minerals, but a more careful study of the sections disposes of this assumption, for the surrounding rim frequently broadens out and merges into a well defined diallage plate (Fig. 3). In consequence of the occurrence of the olivine and augite in the manner described sections of the rock exhibit a

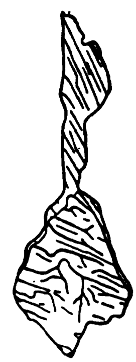


FIG. 3. Olivine partly surrounded by narrow rim of pyroxene, which is continuous with large plate of same mineral. 8803. × ca. 18.

kind of concentric structure, with the rounded olivine grains surrounded by a zone of diallage, and imbedded in a mass of plagioclase. Perhaps the most perfect exhibition of this association of the three minerals is shown in the section of rock No. 1103 from the Cloquet River, where the augite is in such large quantity as to completely envelop the olivine (see Fig. 1).

When the pyroxene is in smaller quantity the rim is much narrower, and in many cases is in its turn separated from the plagioclase by a fibrous growth between the last named mineral and itself. This fibrous growth imitates in great perfection many of the reaction rims described by various investigators [1] as exist-

[1] TORNEBOHM: Neues Jahrb. f. Min., etc. 1877, pp. 267 and 384. A. A. JULIEN: Geology of Wisconsin, vol. 3, p.235, Pl. 22. F. BECKE: Min. u. Petrog. Mitth. 1882.

ing between olivine and plagioclase in many basic rocks. It usually consists of very fine fibres extending perpendicularly from the bounding surfaces of the diallage rim, or when this is lacking, from the peripheries of the olivine grains. In a few instances the fibres form radial groups, centering at points on the exterior of the surrounded mineral. The growth is especially noticeable in the vicinity of the olivine, but it is occasionally also found bordering magnetite grains (Fig. 4) and flakes of biotite. The fact that the fibres are not confined to the borders

FIG. 4. Fibrous intergrowth around magnetite (?) Between the latter mineral and the fibrous rim can be seen a narrow zone of diallage. Section 10439. × 20.

of olivine, but are found as well around magnetite, biotite,[2] and outside of the diallage rims around olivine grains, is presumptive evidence that the growth is not of reactionary origin.

Between crossed nicols portions of the fibrous zone polarize brilliantly, while other portions have the pale blue tint of thin feldspar. Under very high powers the individual fibres are discovered to be discontinuous. They branch, fork and bend in a fantastic manner, and sometimes stop abruptly, while new fibres begin their courses some distance beyond and continue to the edge

iv., pp. 330, 350, 450. G. H. WILLIAMS: Bull. U. S. Geol. Survey, No. 28, p. 52. M. SCHUSTER: Neues Jahrb. f. Min. etc., B. B. v. p. 451. TEALL: Mineralogical Magazine, Oct. 1888, p. 116. LACROIX: Bull. Soc. France d. Min., 1889, xii., p. 83.

[2] The biotite is probably secondary so that the occurrence of the fibrous rim around it is of little importance as an aid in determining its nature.

of the rim. It is impossible to determine the character of the fibres in the finest rims, but in those in which the structure is coarser, it is learned that two components are present. One is possessed of a high index of refraction, and strong double refraction, and this appears to be continuous with the diallage of the narrow zones interposed between the fibrous growth and the surrounded olivine. The other component penetrates between the pyroxene fibres, and has club-shaped ends. Occasionally the twinning bars of plagioclase may be detected in it, and hence it is assumed to be a triclinic feldspar. The fibrous rim is thus an intergrowth of plagioclase and augite, both of which minerals are normal constituents of the gabbro. In the fibrous rims they have evidently crystallized contemporaneously, whereas in the main body of the rock the main portion of the diallage preceded the plagioclase in its separation from the magma. There is no necessity for regarding the intergrowths as in any way connected with reactionary processes, while there is abundant reason for believing them to be due solely to the tendency of simultaneously crystallizing minerals to mutually interpenetrate each other. This tendency is well recognized as existing to a marked degree between quartz and orthoclase, whereby granophyre is formed, and to a less extent between various other minerals. Micropegmatitic intergrowths between hornblende and feldspar, for instance, have been described by Lévy,[1] Camerlander[2] and Lacroix,[3] between hornblende and quartz by Kalkowsky,[4] between garnet and feldspar by Becke,[5] and between garnet and quartz by Lacroix (l. c., p. 317,) between diopside and quartz by Lévy,[6] and between various monoclinic pyroxenes and plagioclase by Becke (l. c.), Camerlander (l. c.), Lacroix (l. c., pp. 316 and 318), and Lévy.[7] In the Minnesota rock the diallage in many

[1] Bull. Soc. Min. d. Fr., 1878, p. 41.
[2] Ref. Neues Jahrb. f. Min., etc., 1888, II., p. 52.
[3] Bull. Soc. Franc. d. Min., 1889, XII., p. 319.
[4] Gneissformation, des Enlengebirges, p. 41.
[5] Min. u. Petrog. Mitth. 1878, p. 406.
[6] Bull. des Serv. d. l. Carte geol. d. l. France, No. 9, 1890, p. 7.
[7] Ib. p. 7.

instances sends out tongue-like processes that penetrate far into the plagioclase in which the pyroxene is imbedded (see Fig. 5), so that there can be no doubt that the conditions were favorable to the formation of intergrowths between these two minerals during the period when they were separating from the rock magma. The only essential differences between the fibrous

FIG. 5. Diallage plate and olivine grain in plagioclase. The augite in the bend extends out into the feldspar, giving rise to an intergrowth, very like that of the fibrous rim. 8803. × ca. 20.

intergrowths and that illustrated in this figure are, first, the finer structure of the former, and second, its occurrence around the older components of the rock. Neither of these differences is important, however. Only the second needs a moment's consideration.

The position of the fibrous growth around the olivine and other minerals is due not necessarily to the fondness of the intergrowth for this place, but simply to the fact that the diallage, during the earlier stages of its growth, fastened itself to the solid particles in its vicinity and coated them with an envelope of its material. Continuing its growth it formed the encircling rims of this material that are so characteristic of many specimens of the gabbro, and, when the feldspar began to separate it formed with this the granophyric intergrowth. Since the position of the diallage had already become fixed, the intergrowth naturally was compelled to occupy a place just without this and around the minerals which the diallage had already partially or entirely encircled.[1] Though a fibrous intergrowth of pyroxene and plagioclase with the aspect of a reaction rim surrounding the older minerals of a rock is a rare phenomenon, it is not a unique one, for

[1] For fuller description of the intergrowth, see author's paper in Am. Jour. Sci. XLIII., 1892, p. 515.

Camerlander,[1] in 1887, described a similar intergrowth of these two minerals around the garnets of a contact rock from Prachatitz, in the Bohemian Forest, and mentioned that it strongly resembled the kelyphite rims around garnets in serpentine.[2]

Biotite is present in many sections of the gabbro, though not in all. It not only occurs in the neighborhood of magnetite, where this mineral is in contact with plagioclase, but it is sometimes found imbedded in the feldspar and augite, and at other times it forms a mosaic with decomposed diallage. In basal sections it is reddish brown, and in longitudinal sections is light yellow normal to the cleavage, and dark brownish-green, almost opaque, parallel to this structural feature. In all cases it is probably secondary, for, even when it apparently occurs alone, a very close inspection of its sections will often reveal remnants of magnetite grains imbedded in it. This form of the mineral is evidently a reaction product between the magnetite and the plagioclase by which it is surrounded. The remainder of the mica is probably derived mainly from diallage, since when this mineral is perfectly fresh biotite is absent from the rock, and when the pyroxene has undergone any kind of decomposition, little flakes of biotite are intimately intermingled with its undoubted alteration products. In the broad pieces of diallage in which the dark platy inclusions are so common, little flakes and tiny needles of biotite are frequently discovered lining the cleavage cracks, so that such pieces not uncommonly are crossed by two sets of inclusions cutting each other at some acute angle, one set comprising the gabbroitic kinds already described, and the other set the biotite plates along the cleavage cracks.

Magnetite is widespread throughout the rock, but it is not abundant in most sections. It is in small grains, and in tolerably large areas that are broadly rod-shaped or very irregular in outline. In most cases it occurs between neighboring plagioclase

[1] Jahrb. d. K. K. geol. Reichsanst, 37, 1887, p. 117.

[2] The writer is informed by Dr. J. J. Sederholm that intergrowths similar to those occurring in this Minnesota rock are common in Norwegian gabbros and in one from Ylivilska, in Finland. In his university lectures Professor Brögger calls them "coronites."

grains, but sometimes it is included within them. The larger part of the mineral is undoubtedly primary, while a smaller portion is probably secondary. By its alteration it gives rise to biotite, as mentioned above, through reactions set up between it and the contiguous plagioclase, so that often a grain of the magnetite is entirely surrounded by a true reaction rim composed entirely of biotite. Leucoxene decomposition products were not once observed.

Nowhere in the normal gabbro does the magnetite occur in sufficient amount to constitute an ore, but in certain phases of the rock that have lost entirely the gabbro characteristics, it is known to exist in great quantities. Prof. Winchell[1] describes these ores in detail and gives analyses of them; but most of the titaniferous magnetites of this author's gabbro-titanic-iron group do not occur in the normal rock of his basal mass. They are found either in its peculiar phases to be described later, or in the Animikie and Keweenawan coarse-grained diabases, whose magnetite is always highly titaniferous, and in which there is always an abundance of leucoxene. Only a few qualitative tests have been made on the magnetite separated from the gabbro, but they all agree in showing no trace of titanium. If, upon further investigation, it is found that an absence of titanium from the magnetite of the basal gabbro is characteristic for the rock, an important difference will have been discovered as existing between it and the rocks of the interleaved flows of nearly similar composition in the underlying and overlying series.

The only other original component seen in any sections is apatite. This is in the usual form, as colorless, acicular crystals imbedded in feldspar, and in the various alteration products of the diallage and olivine. It is present only in very small quantity.

Quartz is rare as a secondary substance, mingled with other secondary products in the most altered phases of the rock. In one section (No. 8796) it is filled with tiny, opaque, acicular inclusions.

In order to learn something of the limits through which the rock varies in its chemical composition two specimens were

[1] Bull. No. 6. Minn. Geol. Survey, p. 117 and 125.

analyzed by Dr. H. N. Stokes of the laboratory of the U. S. Geological Survey. No. 8589 contains a large proportion of diallage and olivine, while No. 8786 is more nearly of the average composition of the entire mass.

	8589	8786
SiO_2	45.66	46.45
TiO_2	.92	1.19
P_2O_5	.05	.02
Al_2O_3	16.44	21.30
Cr_2O_3	tr.	
FeO	13.90	9.57
Fe_2O_3	.66	.81
NiO	.16	.04
MnO	tr.	tr.
CaO	7.23	9.83
MgO	11.57	7.90
K_2O	.41	.34
Na_2O	2.13	2.14
H_2O at 105°	.07	.14
H_2O above 105°	.83	1.02
Total,	100.03	100.75

The larger percentages of Al_2O_3 and of CaO in 8786 as compared with 8589, and the smaller percentages of FeO and MgO, substantiate the results of the microscopical study. An increase in the proportions of Al_2O_3 and CaO indicates an increase in labradorite, and a decrease in FeO and MgO, a decrease in the iron-bearing minerals olivine and diallage. The variations are somewhat larger than was to be expected in a rock so uniform in structure and so monotonous in composition as that of this great mass, but they are easily accounted for by the local accumulation of certain of its heavier constituents. So far as known there are no "schlieren" in the normal rock nor any other evidences of a differentiation ("spaltung") of its magma before cooling, so that the variations in mineralogical and chemical composition must be looked upon as due purely to accidental causes. Moreover, the differences are not great enough to effect any material impression upon the rock as a whole. Its characteristics are practically identical throughout an area of several thousands of square miles, and are

quite different from those of the comparatively thin flows between the sedimentary layers of the Keweenawan.

Prof. Winchell, in his bulletin on The Iron Ores of Minnesota, asserts[1] that the "gabbro is found associated with red syenite, quartz-porphyry and various sedimentary rocks in northeastern Minnesota, and, indeed, it passes through unimportant petrographic changes into the well known 'traps' of the cupriferous formation, from which it has not yet been possible to separate it by any important lithologic or stratigraphic distinctions." But since Prof. Winchell has included within his gabbro the rocks of Bellissima Lake, Carlton's Peak and the feldspar masses enclosed in the dark trap of Beaver Bay, it is plain that he does not confine his remark to the rock to which the writer is now limiting his attention, viz., the great coarse gabbro which Irving described as the great basal flow of the Keweenawan. This rock, as has been shown, by a study of specimens taken from very many different localities (see list of specimens studied, p. 714) within the area underlain by it, is so very uniform in its characteristic features that no difficulty is experienced in distinguishing its thin sections from those of any other rock in Minnesota north of Lake Superior.

Summary.—The microscopical study of the gabbro of Irving's "basal flow" at the bottom of the Keweenawan in Minnesota reveals a rock which is uniform in texture and composition throughout its entire extent. It is composed of magnetite, olivine, diallage and labradorite as essential constituents, with a little biotite and occasionally a very small quantity of quartz as secondary components. Its structure, or better texture, is typically granitic in that all of its comprising minerals are hypidiomorphically developed, with the plagioclase younger than the diallage. In this respect the rock is essentially different from the so-called gabbros of the thick flows interbedded with the clastic beds of the Animikie series and the Keweenawan group in the same region, for in the latter, notwithstanding the

[1] L. c., p. 124.

coarseness of their grain, the plagioclase is always older than the diallage, and it always possesses in greater or less perfection the lath-shaped sections characteristic of diabasic feldspar. This being the case, it seems possible that the great gabbro of northeastern Minnesota is not a "flow" or a "series of flows," but is the solidified reservoir [1] in which later flows originated or is a batholitic mass, as Winchell[2] has latterly come to call it.

Further field work on the geological relationships of the mass will probably show either that it is a batholite within the Keweenawan series, well down toward its base, or that, like the anorthosites of Lawson it is an eroded "massive" upon the top of which the later Keweenawan beds have been deposited.

LIST OF SPECIMENS OF NORMAL GABBROS STUDIED AND THEIR LOCATIONS.

1103 (338) 400 N. 200 W. S.E. corner Sec. 34, T. 53 N., R. 13 W., Minn.
6007 (1415) S. side Cross Lake, S. side Sec. 29–64–1 W.
(1416)
(1424)
6011 (1126) S.E¼ Sec. 21–64–3 W.
6013 (1127) N.W. side Copper Lake, Sec. 9–64–4 W.
6127 (1171) N.E¼ S.W¼ Sec. 36–65–3 W.
6128 (1172) S.E¼ S.W¼ Sec. 36–65–3 W.
6130 (3203) S.E¼ S.E¼ Sec. 36–65–3 W.
7025 (2091) S. shore Akeley Lake, Sec. 29–65–4 W.
8589 (4025) S. shore of small lake in S.E¼ S.E¼ Sec. 19–63–9 W.
8786 (3520) Near S.¼post of Sec. 35–61–12 W.
8788 (3528) N. shore Birch Lake, 200 paces E. of S.¼post Sec. 24–61–12 W.
8789 (3529) W. side Birch Lake, opposite N.E. arm of lake, Sec. 24–61–12 W.
8792 (3532) N.W¼ S.W¼ Sec. 9–62–10 W.
8793 (4259) N.W¼ S.E¼ Sec. 23–62–10 W.
8794 (3522) On Mishiwishiwi river, near centre Sec. 34–62–9 W.

[1] Cf. *ante*, p. 696.

[2] Bull. No. 8, Geol. and Nat. Hist., Sur. of Minn. Preparatory note, P. xxiv. *et seq.*

8795 (3534) On Mishiwishiwi river, near centre of N½ T. 61–7 W.
8796 (3848) On Mishiwishiwi river, about 2 miles E. of 8795.
8800 (3535) On Mishiwishiwi river, near S. side T. 62–8 W.
8803 (3537) S.E¼ N.E¼ Sec. 7–63–8 W., 250 paces S. of S.E. point of Snowbank Lake.
8869 (4061) S.E¼ Sec. 14–64–7 W.
8896 (3856) N.W¼ Sec. 6–64–5 W.
10000 (3691)
10438 (5068) Half way down W. side Greenwood Lake, Sec. 29–64–2 E.
10439 (5069) Outlet Greenwood Lake, Sec. 33–64–2 E.
10440 (5013) Ca. S.E¼ Sec. 8–59–10 W.
10441 (5014)
10442 (5015)
10443 (5016)
10444 (5070)
10445 (5071)
} In order from S. to N. along a stream running from a small lake northward into Birch Lake. First specimen from about N. side of T. 59 R. 10 W.
10537 (5160) S.E¼ S.W¼ Sec. 33–65–5 W.
10538 (4985) S.E¼ S.E¼ Sec. 32–65–5 W.
10539 (4986) S.W¼ S.E¼ Sec. 32–65–5 W. East end of portage between lake Kabamitchikamak and small lake in Sec. 32–65–5 W.
10569 (5181) 1200 paces south N.W. corner Sec. 29–65–4 W.
10570 (4995) 1500 paces S. of N.W. corner Sec. 29–65–4 W.
10638 (5242) North of centre of Sec. 18–64–3 E.

SHOWING APPARENT REACTION RIMS.

6130 (3203), 7025 (2091), 8792 (3532), 8793 (4259), 8795 (3534), 8800 (3535), 8803 (3537), 10000 (3691), 10439 (5069), 10442 (5015), 10444 (5070).

NOTE.—The first number given in each case is the number of the specimen in the collection of the Lake Superior Division of the U. S. Geol. Survey. The numbers in parentheses are those of the corresponding thin sections.

W. S. BAYLEY.

WATERVILLE, ME., July 1, 1893.

Correction.— In the reference (on page 591 of this Journal) to Dr. Wadsworth's work on the Intrusive Basic Rocks of the Marquette region, the date of the publication of the "Notes on the Geology of the Iron and Copper Districts of Lake Superior," is given as 1881. It should be 1880.

It is also stated on the same page that Wadsworth declared these rocks to consist largely of diabase and coarse basalt, both massive and slightly schistose. It was, of

course, not intended by the use of the word "slightly" to intimate that the author did not recognize the true nature of the green-schists of the region. It is well known that in the article referred to that he emphasized particularly the fact that the schists are metamorphosed basic eruptives. He also showed that many of the rocks which still preserve their diabasic and basaltic characters are nevertheless "slightly" schistose, and it is this fact to which it was desired by the writer to call especial attention. This correction is made to prevent misapprehension of the writer's attitude toward the valuable contributions of Dr. Wadsworth to our knowledge of the greenstone-schists of the Lake Superior region. Vide also: Report of the State Board of Geological Surveys for the years 1891 and 1892. Lansing, 1893. Pp. 124–125 and 133–141.

W. S. B.

ON THE GEOLOGICAL STRUCTURE OF THE MOUNT WASHINGTON MASS OF THE TACONIC RANGE.

(With Two Plates.)

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THAT portion of the Taconic Range which is known as Mount Washington is both topographically and geologically a unit. It covers an elongated elliptical area, about fifteen miles in length and four and one-half miles in average breadth, lying in the states of Massachusetts, Connecticut and New York. It occupies the entire township of Mt. Washington, and portions of Sheffield and Egremont in Massachusetts; about one-third of Salisbury in Connecticut; and portions of Northeast, Ancram, Copake and Hillsdale in New York.

Topography.—The Mt. Washington mass is a double ridge enclosing a summit plain. Mt. Everett, or the "Dome of the

Taconics" (2624 feet) lying in the eastern ridge, is the highest peak and one of the highest elevations in Massachusetts, while Bear Mountain (2355 feet) is the highest point of land in the state of Connecticut. The main summit plain is situated to the northward of the center of the mass and has an average altitude of about 1700 feet. Corresponding with the elliptical outline of the mountain, this plain is compressed at the north and south, so that its length is about three miles and its breadth two miles. Encircling it is a line of peaks ranging from 1900 to 2600 feet in height. This encircling wall of peaks is buttressed by other peaks both to the northward and southward, the southern side being strengthened by a parallel belt across the mountain, composed of Mts. Bear, Gridley, Frissell and Monument. Southward of this belt of hills the elevated plateau recurs, but without the rampart of peaks which characterize it in the northern and more central area.

The Salisbury-Sheffield valley on the east and the Copake Hillsdale valley on the west of the mass, constitute a floor having an average altitude of 700 feet, from which Mt. Washington rises abruptly, the mean slope-angle being about 20°. The southern boundary of the mountain is the nearly east and west valley

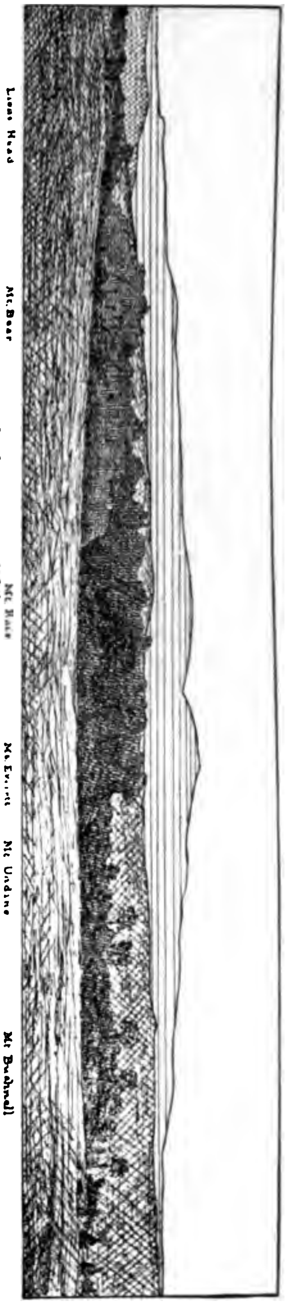


FIG. 1
MOUNT WASHINGTON, MASS.
FROM THE EAST

through which runs the Central New England and Western Railroad. On the northwest Mt. Washington is merged into the narrow ridge of the Taconics, which extends northward into Vermont. The name Mt. Washington, however, applies properly to all of the range lying south of the South Egremont-Hillsdale turnpike. The regular elliptical contour of the mass is broken on the northeast by two deep embayments, the eastern one containing Fenton Brook, and the western, which is knee-shaped, being occupied by Sky Farm Brook. The regularity of contour is further interrupted by an outjutting spur on the west side, known as Cook's Hill. South of the topographical break which limits the mountain in the neighborhood of Ore Hill, the range of the Taconics pursues a more interrupted course, the hills becoming smaller and spreading out considerably.

Previous Work within the Area.—As the aim of this paper is mainly to deal with the problem of mountain structure, no mention will be made of the part which the area has played in the "Taconic Controversy," except as structural facts may be brought out by it. The boundary between the basement limestone and the schistose rock of the mountain was roughly located by Hitchcock[1] for the northern portion, and by Percival[2] for all but the extreme northern portion of the mountain. The former gives (Plate 55 E of the work cited) a section across Mt. Washington, in which the schist and limestone of the east base of Mt. Everett are shown dipping at a steep angle east. Mather[3] gives two sections across the Taconic Range in the vicinity of Mt. Washington. One of these (loc. cit. Pl. XIV, Fig. 1) is from Hillsdale, N. Y. to Egremont, Mass., and passes a little to the north of Mt. Washington; the other (Pl. XVI, Fig. 3) is from Hudson, N. Y., to the southwest corner of Canaan, Ct. The latter crosses the mountain in a northwest-southeast direction and exhibits a synclinal structure.[4]

[1] Geol. of Mass., EDWARD HITCHCOCK, Amherst and Northampton, 1841, Frontispiece Map.

[2] Rept. on the Geol. of the State of Connecticut, J. H. PERCIVAL, New Haven, 1842, Frontispiece Map.

[3] Natural History of New York, pt. iv. Geology, pt. i. 1845.

[4] In his list of dip and strike observations MATHER includes several from the Mt. Washington area (pp. 612–613).

In 1864 James Hall and Sir William Logan[1] visited Mt. Washington and described it as probably synclinal in structure.

The only investigator, however, who has made a detailed study of the geological structure of the mountain is Professor J. D. Dana, whose papers on the subject have appeared mainly in the American Journal of Science. His first paper dealing with the structure of Mt. Washington[2] appeared in October, 1873. It contains a sketch-map with dip and strike observations. On page 38 he states:

"*Mt. Washington is a synclinal with limestone below and slate above.*"

And on page 39:

"We thus find evidence of a very broad synclinal across the center of Mt. Washington. But just north, in Egremont, the structure is totally different: the ridges S and T[3] are the sources of very steep and comparatively narrow independent synclinals with the axial plane inclined westward. * * * The synclinals S and T become merged in one mass in Mt. Washington; and as the limestone does not appear at the smmmit, the intermediate anticlinal in the mountain was only an anticlinal of slate. In other words, the synclinal of limestone beneath the mass of the mountain was one great trough with breaks and incipient flexures; while to the north these incipient flexures became two defined synclinals, with the intermediate anticlinal — the synclinals being courses in the ridges S and T and the anticlinal that of the limestone outcropping between; and then, farther north, there was formed the Taconic synclinal T alone."

In the same year there appeared in the Proceedings of the American Association a paper entitled "The Slates of the Taconic Mountains of the age of the Hudson River or Cincinnati Group.[4] In this paper Professor Dana states that limestone dips west under slates along the east slope of Mt. Washington for four miles, "that is, the whole eastern front." He describes

[1] Paper read by T. STERRY HUNT before the Natural History Society of Montreal, October 24, 1864. Reviewed in the American Journal of Science, 2d ser., Vol. xl, p. 90 (1865).

[2] On the Quartzite, Limestone and Associated Rocks of the vicinity of Great Barrington, Berkshire county, Mass., J. D. DANA, American Journal of Science, 3d ser., vol. vi., p. 37.

[3] The ridge S is that of Mts. Darby, Sterling and Whitbeck, and the ridge T that of Mts. Prospect and Fray near the New York-Massachusetts state line. (Cf. map pl. i).

[4] J. D. Dana, Proc. A. A. A. S., 22d (Portland) meeting, 1873, pp. 27–29.

the mountain as composed of two close-pressed synclinals in the Mt. Washington plateau with steep easterly inclined axes, and that these synclinals are synclinals of slate riding over a single synclinal of limestone.

In 1877, in a paper entitled, "On the Relations of the Geology of Vermont to that of Berkshire,"[1] he adds, referring to the anticlinals of limestone between the three northern spurs of the mountain:

"It has not been possible to follow these subordinate anticlinals southward, because the limestone is not continued far in that direction, and the summit of the mountain is under soil and cultivated farms. But yet the fact of flexure at the north end is strong reason for believing that similar flexures, if not the same continued, characterize the whole length from north to south of the mountain-mass, such a slate easily flexing under uplifting lateral pressure. This is further sustained by observations proving that other subordinate anticlinals exist on the western slope of the mountain, in the vicinity of Copake Furnace. Close to the western foot there are two nearly parallel limestone areas, parallel to the axis of the range. The inner (or more eastern) one is about a mile long, and the other about half a mile. They are separated from one another by a thin belt of hydromica slate, and the same slate exists on the other sides. The dip of the beds of limestone and slate is to the eastward 50°, the strike averaging N. 15° E. (true). They are evidently registers of local folds—anticlinal and synclinal, the former bringing up the limestone."

In the paper "On the Hudson River Age of the Taconic Schists,"[2] Professor Dana has put on record new observations showing the synclinal character of the mountain (l. c., p. 376) and printed a map including a part of Mt. Washington (p. 379)[3].

Another paper, "On the Southward Ending of a Great Synclinal in the Taconic Range,"[4] is specially devoted to a consideration of the structure of Mt. Washington, and contains a map of the southern portion of the mountain on a scale of eight-tenths of an inch to the mile. Professor Dana's earlier conclusions as to the synclinal character of the mountain, had been largely drawn from observations made in Massachusetts. The conclusion that the synclinal character of the northern portion of the mountain is continued to the southern extremity, he drew from the fact

[1] Am. Jour. Sci., 3rd ser., vol. xiv., pp. 262–263.

[2] Am. Jour. Sci., 3d ser., vol. xvii., pp. 375–378 (May, 1879).

([3] Cf. also *ibidem*, Supplement to vol. 18, for dip and strike observations).

[4] *Ibidem*, vol. xxviii., p. 268 (Oct., 1884).

that a number of small limestone areas near Lakeville, in which the strata are but gently inclined, are capped by a schist. This schist he believed to be the same as the schist of the southern extremity of the mountain. He says, speaking of these areas (p. 272):

"Since the limestone is the underlying rock, they are all, if not monoclinal, as is hardly possible, small overturned anticlinals, which have had their tops worn off so as to show the limestone beneath." * * * * * *

"The synclinal structure of the mountain is apparent also along portions of the southern edge of the schist. At Ore Hill, one and a half miles west of Lakeville, the schist overlies limestone."

On page 273 he says:

"The ore-pits that have been opened about the base of Mt. Washington, fourteen in number, are situated near the junction of the limestone and schist, and in view of the facts that have been mentioned, this means—*near where the limestone emerges from beneath the schist.*"

Referring to the dying out of the synclinal to the south of the mountain, he says:

"Again the pitch of the beds in the last three miles is southward in some parts, instead of eastward or westward, showing a flattening out of portions of the synclinal and subordinate anticlinals."

"It thus appears that in the dying out of the synclinal, besides a flattening of portions of the general synclinal and the introduction of southward dips, there was also a multiplication of small subordinate flexures."

"Farther there is a multiplication of ridges of schist in the limestone area."

"Several such ridges, some quite small, are situated, as the map shows, southeastward of the mountain near the village of Salisbury; and others occur farther east. They consist of the same mica schist as the mountain,—they have generally an easterly dip, often a high dip; and the facts seem to show that most of them are *synclinal* flexures; that they occupy the troughs of local synclinals in the limestone; * * * . Most of them were, apparently, half-overturned troughs so pushed over westward that the dip of the schist is generally eastward." * * * * * * *

The following is quoted from a paper[1] entitled "Berkshire Geology" (pp. 15–16):

"The Mt. Washington schists lie in a trough very much like that of Greylock, but one relatively shorter in its narrowed part and reversed in position. In the northern half the trough is a very broad shallow one, while to the south the east side is pushed up westward."

[1] Berkshire Geology, by Prof. JAMES D. DANA. A paper read before the Berkshire Historical and Scientific Society of Pittsfield, Mass., February 5, 1885. Pittsfield, 1886.

In Professsor Dana's last series of papers[1] on the Taconic Area, he adds some strike and dip observations and prints a more complete map of the area. In the second of the papers,[2] on pages 439–442, he describes the variations in character of the schist of Mt. Washington as showing a more intense degree of metamorphism in the eastern portions, and in conclusion states (p. 441): "The facts here reviewed relate, it should be remembered, to a single stratum, that overlying the limestone."

The several extracts above given will, I think, sufficiently explain Professor Dana's views regarding the structure of Mt. Washington.

On the geological map of the Taconic area compiled by Mr. C. D. Walcott,[3] the Mt. Washington mass is indicated having the same relations to the rocks of the adjoining areas as is shown on Prof. Dana's map.

Conditions and Progress of the Present Investigation.—The writer made a partial reconnaissance of Mt. Washington in the season of 1889, but the mapping was largely done during the months of July and August, 1891. He was assisted during the season of 1891 by Mr. Louis Kahlenberg, at present instructor in chemistry in the University of Wisconsin. Mr. Kahlenberg has traced the contact of schist and limestone along the west base of the mountain. The work has been in charge of Professor Raphael Pumpelly, then chief of the Archean Division of the U. S. Geological Survey.

The reconnaissance of 1889 was made on the southeastern flank of the mass and furnished only equivocal evidence concerning the relations of the "Stockbridge" limestone of the valley to the schist of the adjacent flank of the mountain. One of the first results of the work of 1891 was the discovery of a calca-

[1] On Taconic Rocks and Stratigraphy, with a Geological map of the Taconic Region, J. D. DANA, Am. Jour. Sci., 1885 and 1887.

[2] *Ibidem*, 3d ser., vol. xxix., June, 1885.

[3] The Taconic System of Emmons, and the Use of the Name Taconic in Geological Nomenclature, by CHAS. D. WALCOTT, Am. Jour. Sci., vol. xxxv., pl. iii. (May, 1888).

reous horizon occupying the central Mt. Washington plateau, and the locating of its boundaries (cf. map). Observations were then made a little to the north of Salisbury village which showed conclusively that the schist of that vicinity is *below* the limestone, the structure of the mountain at that latitude being essentially an anticlinal. On examining next the northern extremity of the mountain, observations were quite as conclusive in proving that the schist of Jug End is *above* the valley limestone, and that the section across the range at this latitude is essentially what Professor Dana has described. This knowledge that we have to do with two horizons of schist, the one lower and the other higher than the limestone of the Egremont valley, was soon followed by the discovery of lithological differences between the different beds, which have furnished the key to the structure. Topographical features soon suggested a course across the mountain through which the limestone might pass and separate the upper schist of the northern portion from the lower schist of the southern portion. Through this path the calcareous horizon of the Egremont valley, considerably modified it is true, has been carefully traced. A large number of observations have been gathered from all parts of the mountain mass. Each of the numerous peaks has been ascended and as many data as practicable have been collected. At this time the southern portion of the mountain had not been carefully studied. Later in studying the area lying to the east and southeast of the mass of Mt. Washington, it was found that the limestone of that section is divisible into two beds separated by a schist, which is lithologically identical with the lower of the two horizons of schist in Mt. Washington. The evidence supporting this and the manner in which the areal relations are illusive in the indications which they afford regarding stratigraphy, will be set forth in a later paper. The lower of the two limestone horizons was found to extend westward and disappear under the schist of the south end of Mt. Washington. The schist overlying it, which so resembled the lower of the Mt. Washington schists, was also traced along the northern border of the limestone into the southern portion of Mt. Washington. The areal

relations in the vicinity of the mountain are set forth on Plate III.

Horizons Represented.—The Mt. Washington series thus consists, not of two members as supposed by Dana, but of four, two of which are calcareous. The calcareous beds alternate with the schists, which have been shown to possess marked lithological differences. The sequence of these beds is as follows: (a) a calcareous horizon which I designate the Canaan Dolomite from its typical development at Canaan; (b) the lower schist bed, which I call the *Riga Schist* from Mt. Riga peak where it is perhaps most typically developed; (c) a calcareous horizon, which I designate the Egremont Limestone from its wide extent in the Egremont valley (this limestone is much modified in all localities above the valley floor); and (d) the upper schist horizon, to which I give the name *Everett Schist* since it assumes its maximum thickness within the area at Mt. Everett. It will be noticed that this sequence corresponds with that which Dale has determined for the Greylock mass in northern Berkshire county.[1] Below are given in parallel columns for comparison the series of Mt. Washington and Greylock:

Mt. Washington Series.	*Greylock Series* (*Dale*).
1. Canaan Dolomite.	1. Stockbridge Limestone.
2. Riga Schist.	2. Berkshire Schist.
3. Egremont Limestone.	3. Bellows Pipe Limestone.
4. Everett Schist.	4. Greylock Schist.

These beds are probably Ordovician though the lower portion of the Canaan Dolomite may, like the Stockbridge Limestone, be Cambrian.[2] No fossils have as yet been found in the vicinity and it is hoped that further search may reveal them. Walcott[3] has

[1] The Greylock Synclinorium, by T. NELSON DALE. Amer. Geologist, July, 1891, pp. 1–7. Also given in detail in a forthcoming monograph of the U. S. Geological Survey, by Professor RAPHAEL PUMPELLY.

[2] On the Lower Cambrian Age of the Stockbridge Limestone, by J. ELIOT WOLFF, Bull. Geol. Soc. Am., vol. ii. 1891. See also DALE, *ibid.*, vol. iii, pp. 514–519.

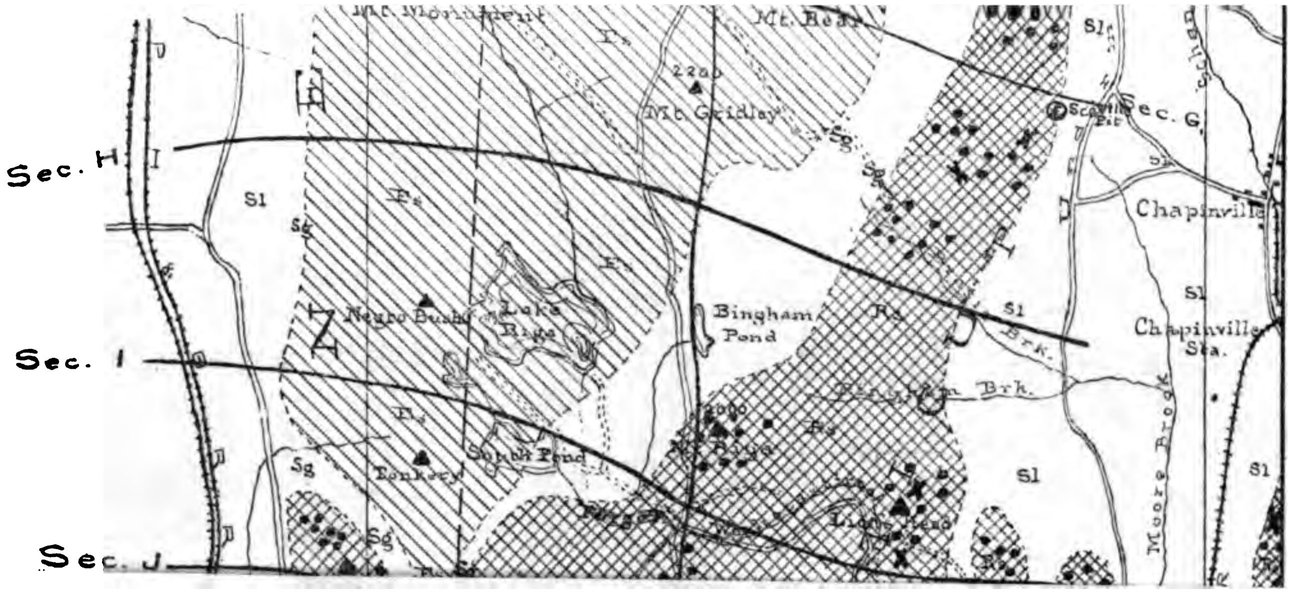
[3] The Taconic System of Emmons, and the use of the Name Taconic in Geological Nomenclature, by CHAS. D. WALCOTT, Am. Jour. Sci., vol. xxxv, pp. 237–242, 399–401, March and May, 1888. (With map).

found Ordovician fossils in the limestone belts some distance t the north and Cambrian fossils at Stissing Mountain to the south west.

Lithological Character of Horizons.—(a) *Canaan Dolomite.* Thi bed seems to be very rich in magnesia, the rock being in som cases at least a true dolomite. This is shown by a number c analyses of it by Mr. J. S. Adam.[1] This rock appears at the sur face only in the extreme southeastern portion of the area her considered, where it presents few features different from thos which are common to the Egremont Limestone. Farther to th eastward, however, and particularly in the vicinity of Canaan, is often characterized by the presence of interesting metamorphi minerals, the well known salite and tremolite of that locality Phlogopite also has in one or two instances been found. In it upper layers, where it approaches the overlying Riga Schist, th rock may become graphitic, as at Ore Hill. As it appears in th vicinity of the mountain, however, the rock presents no charac ters which can be relied upon to distinguish it from the highe Egremont Limestone, and the differentiation is based on strati graphy alone.

(*b*) *Riga Schist.*—This horizon is tolerably uniform in charac ter, the principal differences being in the presence and variabl size of the metamorphic mineral individuals. Strictly speaking the rock is a gneiss, owing to the abundance of feldspar, but i order to distinguish it from more feldspathic and more or les granitoid gneisses lying east of the Housatonic River, it is bes to refer to it as a schist, which it most resembles in structure. I almost invariably is porphyritic from the presence of lenticula to spherical grains of an acid plagioclase. The base is usuall composed of feldspar, quartz, and a colorless mica (in part seri cite) and biotite. Considerable graphite often exists in this bas as does also ilmenite. Chlorite when present is usually in smal amount. Garnets, staurolite, ottrelite, and biotite, as well a plagioclase, are developed at many localities. On the summi of the Lion's Head the rock contains garnets (rhombic dodeca

[1] See Am. Jour. Sci., vol. xlv. p. 404, foot note.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Moore Brook
Bingham Pond
Lake Rige
Tonkery
Brk.

hedra) over a centimetre in diameter, and staurolites (usually inclined-cross twins) a centimetre or more in length. Tourmaline occurs only in minute crystals, much less widely distributed than any of the other metamorphic minerals except ottrelite. Some of the localities where macroscopic garnets and staurolites were found in the rock have been indicated on the map—small black circles and crosses standing for the two minerals respectively.

(*c*) *Egremont Limestone.*—This horizon as developed in the valley near the base of the mountain, is a white to gray crystalline limestone, which is often quite pure but for small scales of colorless mica and grains of pyrite. Locally it contains thin quartzitic or schistose layers. Generally it passes upward into the Everett Schist of the flanks of the mountain through a graphitic layer of variable thickness, and a similar graphitic rock is also to be found at its lower contact with the Riga Schist. As met with in the summit plains, the limestone appears under two modifications which grade insensibly into one another. They are (1) a very micaceous limestone or calcareous mica schist; and (2) a graphite schist, often, though not always, calcareous. The first mentioned modification is to be found only in the central portions of the northern summit plain, where the larger streams have cut through the thick drift deposits. It is richest in calcite at two localities, one of which is in the bed of Wright Brook about midway between its confluence with Ashley Hill Brook and the north and south road to the east, and the other is in the bed of City Brook. This rock also occurs in the small brook near the house of H. F. Keith, in the bed of Huckleberry Brook, and at several localities on the Ashley Hill road between Huckleberry and Wright Brooks. It always contains a silvery mica, graphite and pyrite.

In the northern summit plain graphitic schist (here generally calcareous) forms a border separating the micaceous limestone from the Everett Schist which surrounds it. According as it occurs nearer the limestone, it is the more calcareous. In the lower course of Wright Brook it contains layers of calcite over a

centimetre in thickness, while on the road encircling the west flank of Mt. Everett it hardly effervesces at all with acid. At localities south of the central plain the rock only rarely exhibits effervescence with acid. The graphite schist differs from the limestone not only in the large proportion of graphite and the correspondingly small amount of calcite which compose it, but its least calcareous varieties contain also much feldspar and quartz. Garnets and tourmaline have each been found in one specimen, the first near the lower, and the second near the upper schist contact.

(*d*) *Everett Schist.*—The rock of this horizon is not in all cases to be easily distinguished from the Riga Schist. Like that rock it is porphyritic from lenticular feldspar grains, but these feldspars are much more abundant and more constant, and the base is generally more chloritic or sericitic. Ottrelite is found sparingly at some localities. The most striking lithological difference from the Riga Schist, however, exists in the ***entire absence of macroscopic garnets and staurolites from this horizon***, not an individual of either species having been found within the entire length and breadth of the area of this horizon exposed, though they have been carefully sought at each locality. The beds seem to become more sericitic along the northwestern foot of the mountain. A phase of the rock which is more characteristic of the southeastern portions of the area is very chloritic with magnetite octahedra sometimes as large a pea. Chloritic phases of the rock also appear in the extreme northern areas.

Explanation of Map, Areal Geology.[1]—The eastern and southern portions of the map are based on the Sheffield and Cornwall sheets of the topographical map of Massachusetts and Connecticut by the U. S Geological Survey, and the portion of the map lying in New York State is compiled from older road maps. The manner in which the Egremont Limestone crosses the mountain separating the Everett and Riga Schist horizons, may well be emphasized by special description. On the eastern side the course of the calcareous horizon as it gains the summit plain is

[1] See Plate III.

suggested by topography. The series of sections in Figure 2 will show this in some measure.

Beginning with Mt. Everett, we find that it presents a uniformly steep eastern slope of Everett Schist, the limestone being in contact near the Undermountain Road. Where the slope of Mt. Race begins a little farther south, an abrupt recession occurs in the face of the range, which extends west to the foot of steep cliffs and south to the road north of Sage's Ravine. Into and

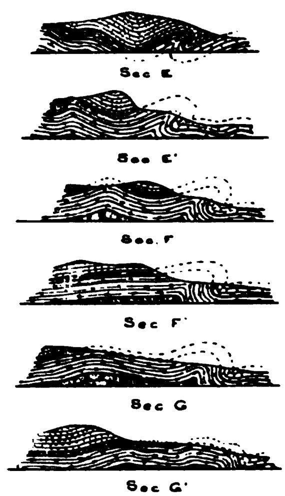


FIG. 2. Series of sections from the east flank of Mt. Washington, showing how the limestone of the valley gains the summit plain.

along this "bench" runs the Egremont Limestone. Proceeding southward from the north end of this "bench," a tongue of schist is met lying within the limestone, about midway between the cliffs and the road, and forming a backbone, the slope immediately west being very gradual while that to the east is tolerably steep. This tongue of schist broadens to the southward, narrowing that belt of limestone which lies to the west of it. As this limestone belt becomes narrowed toward the south, it ascends the mountain, losing as it does so most of its calcite and developing into a black graphitic schist. This reaches the altitude of the summit plain about one-eighth of a mile north of Bear Rock

Falls. From there it is traced with some difficulty along the road to Sage's Ravine, between garnetiferous schists on the east and Everett Schists on the west. The garnets of the eastern schist belt were found to extend northward into the contracted part of the tongue of schist. Immediately north of Sage's Ravine the graphitic rock is distinctly calcareous. West of this point the garnetiferous rock occupies the bed of Sage's Ravine as shown on the map and in sections, while the Everett Schists occur on the road above. To the south of Sage's Ravine and at the altitude of the summit plain, opens a wide bench fully a quarter of a mile in width with the Everett Schists rising abruptly from its western edge in Mt. Bear. To the east of it are thin caps of Everett Schist, then small outcrops of graphitic schists, alternating for a short distance with garnetiferous and staurolitic schists, and finally the latter occurs alone, clearly showing that in the bench and for some distance east of it, the thin bed of graphitic schist lies at the surface. These relations are exhibited in section G′ of Fig. 2. Still farther south this bench is extended into a broad swampy tract on the two sides of which the two schist horizons are shown in outcrops, the garnetiferous rock being on the east and the other schist on the west. This swampy plain outlining the area occupied by the graphitic belt, crosses the north and south Mt. Riga road just north of Mt. Riga (Bald Peak), its northern and southern limits being marked by sharp turns in the road and abrupt rises in the land, as well as by outcrops of the two schist horizons. In the almost continuous areas of exposures in the vicinity of the Mt. Riga Lakes, its course is carved out sharply though the rock is not found in outcrop. Beyond South Pond the belt narrows and begins to be followed with difficulty. The graphitic rock has been found in outcrop in the bed of a stream flowing toward Mt. Riga Station. Farther down this stream is joined by another from the east flank of Mt. Thorpe, containing likewise a belt of graphitic schists (here calcareous) in contact with garnetiferous rock on the west. This belt of graphitic rock is soon cut off to the south, but it is found to join the main valley through a depression of the ridge to the north-

east of Mt. Thorpe, whence it continues northward as a transitional zone between the valley limestone and the Everett Schist. The rock of Mt. Thorpe is filled with garnets, and the area of schist east of the easterly branch of the stream has also abundant garnets, though they have only been found at some distance from the graphitic rock. Between the two forks of this stream, the upper schist rests as in a saddle, its southern termination being a small triangular hill. The southeastern portion of the map, which exhibits areal and structural features of much interest, will receive fuller treatment in another paper, which will deal with the structure of the area to the southeast of Mt. Washington.

Method of Constructing Sections.—The lines of sections have been made as nearly as possible perpendicular to the strike of the strata. The strike has been obtained either by actual measurement with the compass at the locality, or from the directions of the boundaries of horizons. The curvings of the section lines must therefore indicate, either that the crest or trough lines are inclined (pitch) or that the flexures are of variable width. To the southward of section E the average pitch is found to be northward, as shown by the areal relations, and as indicated in the steep southern and gradual northern slopes of the "Lion's Head."[1] To the north of section E the convexity of the section lines towards the south is explained both by southerly pitch and by a greater compression of the flexures in the northern portion. Southerly pitch is suggested by the topography of Mts. Everett and Undine, as well as by the pitching trough and crest lines of coarse corrugations on the slope that rises at the south end of Guilder Hollow (cf. reference to Dale below). These facts when taken in connection with the sections (Plate IV), show the mountain to have a general basin structure.

The determination of the dip is made with great difficulty within the area studied, since the lamination indicative of the plane of bedding is often obscured or even obliterated by subse-

[1] For the detection of pitch by the contour of an elevation I am indebted to Professor Pumpelly for suggestions. He was, I think, the first to discover that these contours betray in an important manner the inclination of the trough and crest lines of folds.

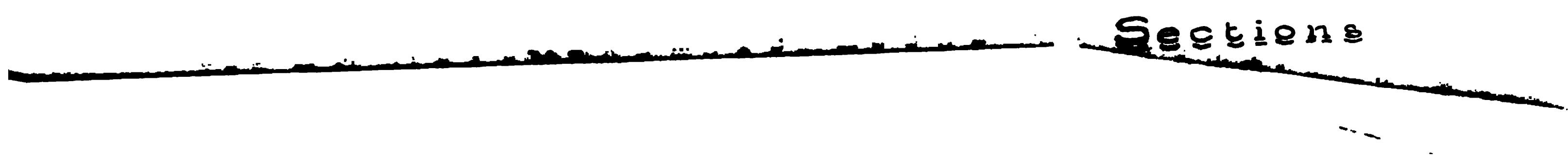
quently induced cleavage structure. In this particular the problems have been essentially those which were encountered in the Greylock area, and similar criteria have been made use of to distinguish the planes of stratification.[1] Hence with the exception of those localities where contacts of the different rocks are exposed, dip observations have been possible at only a few localities where definite plications could be made out.

In the absence of dip observations, the sequence being known, many structural facts have been deduced from the areal relations of the several horizons. Next in importance as a method of determining structure is the interpretation of topographical features. It is by application of all of these methods, whose relative importance is expressed by the order in which they have been mentioned, that the sections have been constructed.

The longitudinal section (Fig. 3) which passes through the mountain in a general north and south direction, nearly at right angles to the cross sections just described, is constructed to show how the northerly pitch of the southern portion of the mountain carries the Canaan Dolomite and the Riga Schist so low that they do not appear again to the northward, for although the pitch in the northern part of the area is southerly, it is not sufficient to entirely counteract the very considerable northerly pitch of the southern portions of the mass.

Structure of the Mountain.—The sections show that the southern portion of the mountain is a geo-anticlinal in the Riga Schist, probably with moderate minor folds tolerably symmetrical. Within the core of this anticlinal is the Canaan Dolomite, which appears from under the schist to the southeast of the

[1] An extensive study of the subject of secondary cleavage as it is met with in the Greylock area, has been made by Mr. T. Nelson Dale, and will appear in full in a monograph by Professor Pumpelly on the Geology of the Green Mountains. A summary of his observations and conclusions is contained in the American Geologist for July, 1891. Mr. Dale has also published a paper entitled, "On Plicated Cleavage-Foliation," in the American Journal of Science for April, 1892. As the writer assisted Mr. Dale during a portion of the field investigation, he became familiar with the structures there exhibited, as he did later also in independent work in the northern stretch of the Taconic Range west of Williamstown.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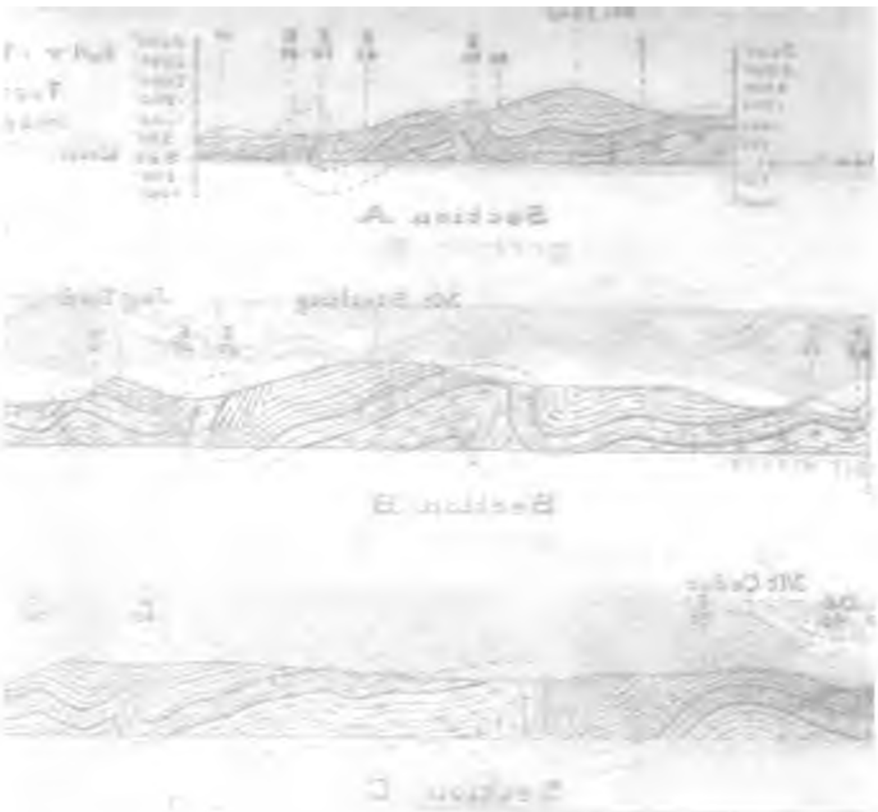
Section A
Section B
Section C

mountain mass. Proceeding northward, one of the minor synclinals in the western limb of the anticlinorium increases in depth and width by a northerly pitch of its trough line, so as to show at the surface, first, the Egremont Limestone, and then more and more of the Everett Schist. The eastern limb of the anticlinal has, in consequence, been narrowed, then compressed and overturned, until east of Mt. Race its axis[1] inclines westward about 35 degrees. The northerly pitch of its crest line carries it continually deeper, until finally it disappears beneath the limestone on the east flank of Mt. Race (cf. Fig. 1). By this process the anticlinorium of the southern portion has been developed in the central portion into a compound fold consisting of two deeply corrugated synclinals (eastern and western schist ridges) and a central corrugated anticlina, which brings the limestone to the surface in the central plain. Proceeding northward still, the flexures sharpen and deepen and become reversed, much as Professor Dana has described. This narrowing of the folds contracts the mountain at its north end, and the succeeding southerly pitching crest and trough lines bring the limestone higher and higher until the overlying schist disappears altogether. To facilitate the comparison of the flexures, Fig. 4 is introduced, the curves being those of the contact of the Egremont Limestone and the Everett Schist as developed in the series of sections. The map, as well as the sections, show that the small schist ridges in the limestone near Salisbury are mainly infolded Riga Schist with the axes of the folds inclined eastward.

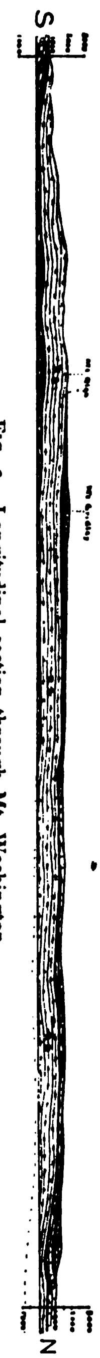

FIG. 3. Longitudinal section through Mt. Washington.

Variable Thickness of the Egremont Limestone.—The upper limestone of Mt. Washington forms the

[1] In this paper the term "axis" is used for the axial-plane bisecting a flexure, and never for the crest line or trough line. Cf. MARGERIE ET HEIM, Les dislocations de l' écorce terrestre. Zürich, 1888, p. 53.

western part of the great belt which Professor Dana has mapped in this section of Berkshire county. While it has not been found possible to accurately measure its thickness, it may be safely stated that the thickness never exceeds 600 to 800 feet, and that the beds thin out toward the south end of the mountain. They

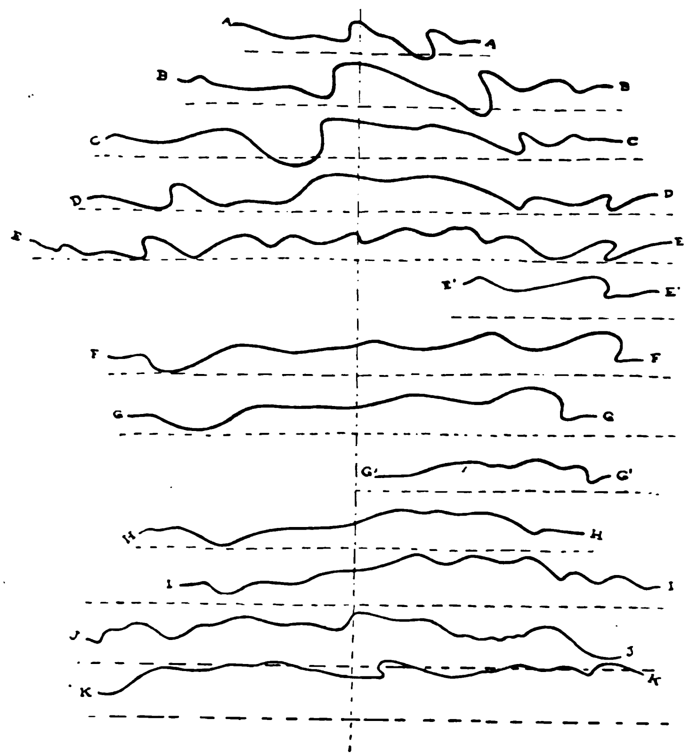

FIG. 4. Series of curves showing the probable form of the flexures in the rocks of Mt. Washington.

also thin out toward the center of the mass from either side. The minimum thickness in the southern portion of the area is probably something less than 100 feet. The general truth of this statement is borne out by an examination of the map and sections (Sage's Ravine, Bear Rock Falls, etc.) As the limestones do not again appear on the southeast flank of the Cornwall-Sharon core of older rocks, it is probable this horizon never

extended much beyond its present limit in a southerly direction. As the bed thins out it becomes more graphitic, indicating also that the conditions attending its formation had here some peculiar local characters.

Metamorphic Character of the Rocks as Indicated by Microscopic Studies.— The microscopic examination of thin sections of rocks from Mt. Washington shows clearly that they are strongly metamorphosed clastics. Evidence has been deduced from the secondary growths of feldspars, garnets, and tourmalines, as well as from the relations of the different metamorphic minerals to one another, to show that the orographic forces to which these minerals owe their development, operated in several more or less distinct periods.[1]

Summary and Conclusions.— What has been set forth in the preceding pages agrees well with Professor Dana's views so far as the northern portion of the area is concerned. In the southern and central portions, however, where the areal and structural relations are more obscure, I have arrived at very different conclusions. This has been due, not to the discovery of errors in Professor Dana's observations, which have been in the main confirmed, but to the collection of a larger number of observations and to the application of some structural principles which were not made use of in his study. A glance at the map will show how perfectly the belt of Egremont Limestone which crosses the southern portion of the mountain, is concealed where it meets the valleys. This belt, the discovery of which furnished a key to the structure, is not at first apparent to the geologist, because at its ends the boundaries of the Riga Schist coincide closely in direction with and form an extension of the boundaries of the Everett Schist.

To summarize briefly the results which have been discussed in the foregoing, the Mt. Washington series consists of four members, which in order of age are as follows: 1) Canaan Dolomite, 2) Riga Schist, 3) Egremont Limestone, and, 4)

[1] Phases in the Metamorphism of the Schists of Southern Berkshire: WM. H. HOBBS. Bull. Geol. Soc. Am., vol. iv., pp. 167–178, pl. 3.

Everett Schist. A somewhat striking lithological distinction, which has been valuable for purposes of identification, is found to separate the two schist horizons, the Everett Schist being entirely free from garnet and staurolite, while the Riga Schist usually (though not always) contains macroscopic crystals of one or both of them. The older rocks are found in the southern portion of the area, a general northerly pitch carrying them successively below the surface as we proceed northward, until at the north end of the mountain we find the upper two members of the series only.

The structure of the mass may be summarized by stating that the beds have been thrown into corrugated folds which seem to have moderate, tolerably symmetrical corrugations at the south end of the mountain, but these corrugations deepen and become frequently overturned as we proceed northward. In the eastern portion of the area the axes of the reversed folds is generally westward. At the extreme south, the structure is a geo-anticlinal, but this develops in the central and northern parts of the area into a geo-synclinal owing to the continued disproportionate deepening and widening of one of its minor western corrugations. The general pitch of the beds is north. A less important southerly pitch which characterizes the northern portion of the area, in combination with the general synclinal structure in cross sections, gives to all the mountain except its extreme southern portion a basin-like character. The rocks are throughout strongly metamorphosed clastics, the orographic disturbances to which they owe their marked crystalline character and porphyritic crystals having operated in several distinct periods. The Egremont Limestone shows a marked diminution in thickness as we proceed southward in the area until it almost disappears. Throughout the mountain plain it is greatly modified, being either a micaceous limestone or calcareous mica schist, or a graphitic schist. The graphitic rock is most developed near the schist contacts and in the southern portion is the only representative of the limestone.

WM. H. HOBBS.

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EDITORIAL.

AT THE recent meeting of the British Association for the Advancement of Science in Nottingham, the section devoted to geology was perhaps the busiest department of the association. Contributions covering nearly all phases of the science crowded the time allotted to the reading of papers. Among them petrology held a prominent position, owing to the eminent character of the president of the section, and to his successful labors in this branch of geology. Mr. Teall based his presidential address upon the data furnished by petrological research, which, to his thinking, lend additional strength to the uniformitarian doctrines of Hutton. By a variety of illustrations he showed the identity of ancient and modern rocks, whether sedimentary, igneous, or metamorphic, and inferred a similarity of physical conditions attending their formation. He emphasized the high degree of differentiation of organic life at the time when the first Cambrian strata were deposited, and maintained that the crystalline schists of earlier age, so far as we have yet become acquainted with them, do not contain the records of the early stages of the planets' history. They can not be considered to represent the primitive crust of the earth. His testimony as to the identity of the volcanic lavas erupted in Paleozoic and Tertiary times in Great Britain, both as regards their structure and composition, allowance being made for subsequent alteration, is significant. It shows that in this region, through a long succession of ages, the groups of rock magmas developed in different periods of volcanic activity have been similar, and that the essential character of the petrographical province did not change.

Sir Archibald Geikie's paper, "On Structures in Eruptive Bosses which Resemble those of Ancient Gneisses," was a valuable

contribution to the study of gneissic structure, since it showed the possibility of a part, at least, of the banding in these rocks being due to a primary banding of igneous masses through some process of segregation or through differentiation of the magma into layers. A parallel banding of igneous rocks in the neighborhood of a plane of contact has been known, but its magnitude is generally inconsiderable. The structure in the gabbro on the Isle of Skye, however, which was described by Geikie, is on a large scale, and without apparent relation to a plane of contact. No attempt was made to suggest a cause for such a mode of segregation, since the study of the locality where it is best developed is not yet completed.

Prof. Brögger's paper, "On the Genetic Relations of the Basic Eruptive Rocks of Gran, Christiania Region," presented an array of facts with regard to the differentiation of rock magmas. By means of chemical analyses and field observations he showed that basic magmas of like composition in neighboring localities had separated into pairs of magmas, which were quite unlike one another chemically; producing dissimilar pairs of rocks. This proves that a given magma may differentiate in more than one manner, according to circumstances. The entire paper is to appear in the Quarterly Journal of the Geological Society.

Mr. Harker discussed the question of magmatic concentration, or differentiation, with reference to its probable cause, and pointed out what seemed to him obstacles to the application of Soret's principle. He suggested that a more probable explanation would be found in Berthelot's principle, or that of maximum dissipativity. The applicability of Soret's principle to the differentiation of magmas is also assailed by Prof. Bäckström in an article to appear in the next number of this JOURNAL, and the principle of liquation advocated. While it is quite probable that all of the phenomena of segregation and differentiation may not be accounted for by one law of diffusion dependent on osmotic pressure, and while this law finds its most perfect realization in the most dilute solutions, and while certain separations of rock magma may take place near the point of saturation, still it can

not be denied that rock magmas at times are known to attain extreme liquidity. Moreover, there must undoubtedly be a number of different physical causes at work conjointly, each of which may preponderate under favorable conditions, so that it is quite probable that no single process will be found adequate to explain all the phenomena in question.

It is interesting to observe that, while the majority of petrologists are engaged in studying the evidences of differentiation of molten rock magmas, the theory of magmatic synthesis proposed by Bunsen is not being wholly neglected. From the nature of a portion of the evidence it is possible to frame diametrically opposite hypotheses, but when all of the conditions are taken into account it would seem that but one of the hypotheses can have a general or far-reaching application. Prof. Sollas's paper, "On the Origin of Intermediate Varieties of Igneous Rocks by Intrusion and Admixture, as Observed at Barnavave, Carlingford," demonstrated how intimately the material of an acid molten magma may penetrate the interstices of a highly fractured rock, in this case basic; the delicate veins thinning to almost microscopic dimensions. Instances of this kind are well known. The assumption, however, that this process has taken place to a very considerable extent, and has produced bodies of rock of intermediate composition, seems to ignore the probable physical conditions under which rock magmas are irrupted, and also the geological probabilities of such things happening. Thus there may be no defect in the logic of the assumption as an abstract idea, but there may be little or no probability of its ever taking place to a considerable extent in nature.

Other petrological papers were presented by Prof. Sollas, Mr. Watts, Dr. Johnston-Lavis, and an interesting account of the volcanic phenomena of Japan was given by Prof. Milne, and illustrated by lantern slides. It cannot be out of place, for one who has been fortunate enough to have been a guest of the Association, to express a high appreciation of the honor, as well as of the generous social hospitality which has become a distinguishing characteristic of these meetings. J. P. I.

Reviews.

Correlation Papers. The Newark System. By ISRAEL COOK RUSSELL. Bulletin 85, U. S. Geological Survey. Washington, 1892.

THIS Bulletin adds another number to the list of invaluable correlation papers, prepared especially for the Geological Survey, but of the greatest service to all professional geologists and advanced students alike. Prof. Russell's paper is of exceptional completeness from the bibliographical side; its index is a marvel of minute reference; every author's name is followed by a complete list of his writings, the more important ones being analyzed; every locality noticed in any paper is indexed separately, with reference to the place of its mention; occurrences of sandstone, shale, conglomerate and trap are catalogued under these headings. Immediate reference may thus be made to any desired item concerning the Newark system, excepting the fossils, which, for some reason, are not indexed under their names, but only through the authors who have described them.

The chief headings of the text are: Nomenclature, area, lithology and stratigraphy, conditions of deposition, life records, associated igneous rocks, deformation, former extent, correlation and summary. A good number of maps serve to guide the reader to the easy understanding of the several areas into which the formation is divided. I can only comment on a few of these subjects.

Professor Russell has done good service in the fourth headings in showing the incompleteness of the evidence on which glacial action has been argued as an agency in the deposition of the formation. Near the margin of several of the Newark areas, heavy conglomerates, containing boulders up to four or five feet in diameter, are known at various localities; and although none of these deposits are unstratified, they have frequently been appealed to as evidence of glacial action. But none of the boulders are scratched or notably angular; all of them are, as far as known, deposited near the shore of their time; all of them are systematically interbedded with ordinary aqueous deposits. Cer-

tainly they are not unaltered glacial deposits; and to assume that they are derived from such is to imply that no agency but glaciers is competent to move boulders of several feet in diameter. Russell refers to the occurrence of large angular rock masses on the alluvial fans of the arid regions at a distance of two or three miles from their source, to show that the movement of large boulders may take place under subaërial conditions; he cites the absence of ice-borne boulders among the finer strata of the Newark deposits; and he argues a relatively warm, not a cold climate, from the prevailingly red color of the formation and from the character of the fossils. Emerson has detected large boulders in certain basal beds of the sandstones in Northern Massachusetts, demonstrably close to their source, and not in the least indicative of glacial transportation. Indeed, to conclude that glacial action occurred at sea level during the period of Newark deposition simply from the coarse nature of certain marginal conglomerates, is to adopt an open alternative instead of a closed demonstration as a guide to belief.

Another line of evidence may be introduced against Fountaine's argument that the Newark conglomerates of Virginia were derived from glaciers which descended from the Appalachian mountains of that time. Local glaciers could originate in that latitude only on lofty mountains, from which they might descend to sea level, much as those of New Zealand do now. But the evidence gathered from the outline of the under border of the Newark areas does not at all favor the idea that they closely adjoined lofty mountains. If such had been the form of the surface whose submergence allowed the accumulation of the Newark sediments, their under border must have been extremely irregular; the Newark waters must have rounded many a bold promontory and penetrated many a deep bay. The basal sediments accumulated along so sinuous a water margin should now show some indication of these promontories and bays. They should be distributed much in the way that the Permian breccias of Wales lie around their once buried and now resurrected mountains, and thus show their origin on an extremely irregular coast. But as far as the basal beds of the Newark system have been studied out, they do not indicate that the surface on which they lie possessed any great relief at the time of their deposition. Whatever deformation it had previously suffered, whatever mountainous heights this deformation produced, the action of erosion had in pre-Newark time carried away enough material to some unknown goal

to leave a surface of only moderate inequality; by no means of such inequality as would gather snow fields on its higher levels, and shed long glaciers down its valleys into the Piedmont seas.

The prevailing red color of the Newark strata is also adduced by Russell as indicative of a relatively warm climate, as contrasted to a glacial climate. To this might be added that the slow subaërial decay, from which red soils and sediments seem to be derived, is inconsistent with the conditions of decay on lofty mountains, from which the detritus is shed rapidly, leaving a relatively large surface of bare rocks; while it is accordant with the idea of a well denuded region, from which further denudation carries material slowly.

In examining the structural relations of the igneous rocks, it is noticeable that little success has as yet attended the efforts of observers southwest of the Delaware to distinguish between the intrusive and extrusive origin of their trap sheets. It would seem from this that the scouring of the decayed surface of the Newark belts by Pleistocene glacial action has been an advantage to the geologist of to-day in New Jersey, Connecticut and Massachusetts; but an advantage that is frequently offset by the sheets of drift which obscure or conceal so many of the weaker strata in the Connecticut valley. I believe that Connecticut alone has yielded a greater number of localities where the contact of the sandstones on the trap sheets can be actually seen, and from which good hand specimens can be secured, than all the areas beyond the Hudson. It may be noted that the map of the New York-Virginia Newark area, compiled by Russell from such data as he could gather together, does not give a correct impression of the crescentic trap ridges of eastern Pennsylvania. I have only examined a small part of that district, but from what was seen and from the topographic maps of the Perkiomen drainage area, surveyed by the Philadelphia water commissioners for a proposed new water supply, I think that an accurate geological map of the district will disclose a more systematic arrangement of forms than now appears.[1]

The deformation of the Newark areas has been a subject for much discussion already, and it will doubtless furnish as much more in the future. Before it can be successfully deciphered, the stratigraphic succession of the system must be made out; and that has not been generally done, as may be seen from Russell's chapter on lithology and

[1] Since writing the above, I have seen the new geological map of Pennsylvania, on which the curved trap sheets are clearly shown.

stratigraphy; in which the various kinds of rocks are enumerated, but in which their succession and thickness is not stated. The difficulty of the problem lies in the monotony of the strata, and in the doubt in many cases as the origin of the trap sheets. Whatever success has yet been gained in solving this problem, it has come chiefly through the aid given by the old lava flows, and only secondarily through ordinary stratigraphic methods. In Pennsylvania and further south, no complete stratigraphic correlations have yet been established; mainly, as has has been stated above, because the trap sheets there are not yet well deciphered. In New Jersey the discrimination between intrusive and extrusive sheets has been well accomplished, but doubt is felt as to the location of fault lines by which they are dislocated, this doubt resulting from the uncertainty as to the reappearance of identical sandstone strata or trap flows. It is only in the Connecticut valley that the variety of trap sheets and associated sedimentary beds is such as to make the demonstration of faults complete. Here, over a considerable share of the area, the stratigraphic succession is made out with much certainty; and the lines of dislocation are determined with sufficient precision. At the same time certain fossiliferous beds, rare in the formation as a whole, and therefore of all the more value in defining horizons, have been traced for thirty or more miles inland from Long Island Sound; and their dislocations agreeably confirm the conclusions previously reached as to the faulting of the trap sheets.

Like so many other features of this peculiar system of rocks, its style of deformation is exceptional. It is nowhere folded in the ordinary manner; where curvature of bedding appears, it is of such character as to give crescentic outlines to the beveled edges of the strata now visible. The formation is, as a rule, tilted over to a rather regular monoclinal attitude; but while the earlier conceptions of its structure implied that the monocline was practically uninterrupted, the later studies show it to be complicated by numerous faults, traversing the mass in various directions, and as a rule systematically arranged, although the control of the system is obscure. One thing is clear: the faults penetrate the crystalline foundation on which the Newark beds lie; they are not dislocations within the Newark beds alone; indeed, it almost seems fair to say that the dislocating forces were indifferent to the cover of Newark beds, and that their action was chiefly expended on a much deeper mass of rocks

The original extent of the Newark areas has been much discussed,

and Mr. Russell, some years ago, espoused the idea that their present surface was a comparatively small part of their original basins. This matter is essentially indeterminate at present; but the valid evidence of great post-Newark erosion disposes me to accept almost any measure of former extension of the system that may be required by reasonable argument. At first, the mind halts before the supposition that vast masses have been uplifted and worn away in the ages since the date of the Newark deposition, but the evidence of vast denudation in that interval is now so complete that it no longer seems warrantable to withhold belief in the "broad terrane hypothesis," either from its extravagant erosion of rock masses, or from an apparent insufficiency of time for such extravagance.

On the other hand, while it seems likely that there was some connection between the several separate Newark areas, because their fauna and flora are so similar, it does not seem necessary to conclude that all the space between the Connecticut and the New Jersey areas was once overspread by Newark strata. It may have been. There was time enough during the Newark deposition to furnish material for such a cover; and there has been time enough since then to wear it away; but still there is no direct evidence that it existed. The original boundaries of the formation are very vaguely defined.

Noticing that a greater definiteness of results has been gained in the Connecticut valley than in the other Newark areas, it is evident that the physical conditions of origin of the trap sheets in the southern areas deserve the closest scrutiny. If they prove to be intrusive sheets, they are of little structural value. But if they are proved to be extrusive, they may then be treated as conformable members of the stratified series, and thus a key to the general attitude of the system is gained. After this step, the detection of sequences of strata, including extrusive trap sheets with the aqueous sediments, is of next importance, as by this means faults may be located, and thus some advance made in the general reconstruction of the formation.

But even where best studied out, it is likely that the cross sections by which underground structure is represented are hardly more than parodies on the facts; so insufficient are the opportunities for the discovery of deep internal structures. A close knowledge of the system seems beyond reasonable expectation.

W. M. Davis.

Harvard College, November, 1893.

Text-book of Comparative Geology. By E. KAYSER, Ph.D. Translated and edited by PHILIP LAKE. Pp. xii, 426. Swan, Sonnenschein & Co., London. (Macmillan).

The translation of Dr. Kayser's book is a welcome addition to the literature of geology in English. Its title is fairly definitive. It is an attempt to bring together, or to set in their proper relations, the results of geological investigation conducted in the various parts of the world. The volume is too brief to allow this to be carried out in great detail. The abbreviation has been effected in part by the omission, or by no more than the merest mention, of results reached in extra-European countries. This is particularly true with that part of the volume which deals with the post-Paleozoic formations. While at first thought this might seem to detract from the value of the volume for American students, we think on the whole it is an advantage instead, if omissions were necessary. Data concerning American geology are more easily accessible to American students than data concerning European geology, which this volume measurably supplies. The volume will find its chief use in America as a convenient reference book of European geology, and as such it should be widely distributed. Its abundance of tables, showing the relations of the subdivisions of the various systems in different countries, so far as they are made out, are especially convenient for general reference.

At several points in the volume there is a noticeable tendency to make unqualified statements where qualified statements would seem to us better. A case in point is the unqualified denial of the organic character of the Eozoon. It is true in most cases, where positive conclusions are asserted, that they represent the best conclusions of the present day, but in some cases they seem to us to represent probable or qualified or tentative conclusions, not demonstrated or absolute or final ones.

All pre-Cambrian rocks are represented as Archean, though the length of Archean time is stated to be so great that the beginning of the Cambrian "may be considered as comparatively a recent event." In spite of this recognition of the importance of the Archean, but fourteen pages are devoted to its consideration. Although different systems are not recognized in the pre-Cambrian rocks, the diversity of origin of different parts of the group is distinctly recognized. The author is inclined to attach less weight to the existence of limestone and graphite in the Archean rocks, as indications of life, than would

most geologists. He thinks that the strongest evidence for the existence of life in pre-Cambrian time is the high organization of the Cambrian fauna. While geologists will be ready to assent to the strength of this last argument, they will hardly be ready to regard it as the only strong reason for belief in pre-Cambrian life. To the very considerable number of fossil forms already found in pre-Cambrian rocks no reference is made.

The important question of the origin of the Archean is rather briefly dismissed. The discussion touching this question is much less full and much less satisfactory than that of Prof. Van Hise, recently published.[1] Indeed, had Prof. Van Hise's discussion been published before Dr. Kayser's treatise, the latter author might have found a way out of some of the difficulties which seem to lie in his mind concerning the origin of the Archean.

An excellent feature of the book is the prefacing of the discussion of each system by a short account of the origin and history of its differentiation from underlying and overlying systems. Each system is discussed under the general heads of — 1) Distribution and development; 2) Paleontology. Under the first head, it could have been wished that the structural relations of the systems had been more uniformly and sharply brought out. Such clear statements as that concerning the North American Devonian system, that it rests "conformably and without break on the Silurian, and is covered conformably by the Carboniferous" (page 111), are not always to be found. Where knowledge does not permit such positive statements, definite statements representing the degree of present knowledge would have been welcome. So, too, the relations of faunal and stratigraphical breaks are not always so clearly set forth as could have been desired in a text-book.

In the discussion of the Permian system, Dr. Kayser brings out the fact of wide-spread conglomerate formations (India, Victoria, Brazil, South Africa) in tropical latitudes and the southern hemisphere, which sometimes contain polished and striated stones very like those of glacial formations of later date. In Africa the Dwyka conglomerate rests on rock, the upper surface of which is smoothed and striated like rock beneath the modern glacial drift. Dr. Kayser indicates that the belief that these Permian conglomerate beds are of glacial origin has gradually gained ground. The flora succeeding the conglomer-

[1] Bulletin of the U. S. Geol. Survey, No. 86.

ate in Africa, South Asia and Australia is characterized by Mesozoic types. This change is believed by many to have been brought about by the cold climate which was the determining cause of the conglomerate beds. Blanford and Waagen go further and connect the decline of the marine Paleozoic types with the cold climate of the end of the Paleozoic.

In the discussion of the Mesozoic and Neozoic there is scarcely any reference to American geology. In connection with the discussion of Pleistocene geology, two glacial epochs are recognized. The author inclines to the eolian hypothesis for the origin of loess.

Both the physical and paleontological phases of the subjects discussed in the volume are illustrated by numerous figures, the former rather less fully than the latter. A series of maps, showing the distribution and relations of the systems described, would have enhanced the value of the volume which is still great without them.

ROLLIN D. SALISBURY.

Iowa Geological Survey. Vol. I. First Annual Report, 1892. SAMUEL CALVIN, State Geologist, Des Moines, 1893. 8vo, 472 pp., 10 plates and 26 figures.

IN addition to brief administrative reports, the first report of Iowa's third survey contains papers by S. Calvin, C. R. Keyes, Assistant State Geologist, S. W. Beyer, H. F. Bain and G. L. Houser.

The introductory paper by Mr. Keyes, on the Geological Formations of Iowa, is a summary of present knowledge of the various formations occurring within the limits of the state. The writer has availed himself of the various studies made of these rocks in recent years, and the result is shown in an improved classification over that of preceding surveys. While all the formations have come under careful study, the most notable progress is shown to have been made in the classification of the Devonian, the Carboniferous and the Cretaceous.

Investigations in northwestern Iowa have brought to light the presence of undoubted eruptive rocks at no great depth below the surface. In Mr. Beyer's paper are given the details relating to the discovery of typical quartz-prophyry, interbedded with sandstone and gravel, in a deep well at Hull, Iowa. The discovery by Culver and Hobbs of eruptive rock within the Sioux quartzite in southeastern

Dakota is referred to, and, following Hall, White, and Irving, the conclusion is drawn that the Sioux quartzite is the oldest formation in the state. Some familiar names have disappeared from the geological section, and their places are assumed by newer but more appropriate terms, as, for example, Oneota for Lower Magnesian, St. Croix for Potsdam, while Hamilton is represented by four names applied to as many subdivisions. The term Augusta is given to the terranes including the Warsaw, Keokuk and Burlington, in place of William's term Osage which is discarded as inapplicable. The Warsaw beds of Hall are here included with the Keokuk, and the term Warsaw dropped. An error occurs in the definition of the St. Louis limestone on page 72, where it is asserted that the brecciated limestone constitutes the base of the beds in Iowa. This is the case only along the extreme margin of the beds. Seaward from the old shore line, as shown along the Des Moines in Van Buren county, the basal member consists of a brown, magnesian limestone in fairly regular, more or less undulating beds. The texture is sometimes nodular and sandy. In thickness the formation varies from five to fifteen feet or more.

The structure of the coal measures is treated in considerable detail, and emphasis is given to conclusions based largely upon Mr. Keyes' investigations in Iowa. These rocks are included in two stages, the lower or Des Moines, and the upper or Missouri formation, White's middle division being discarded. These are not considered two distinct formations in the sense that the lower was deposited prior to the laying down of the upper—the view commonly entertained—but the two were formed contemporaneously, the former as a marginal or shore formation, and the latter as its deep or open sea correlative. The view here advanced seems to be a modification of that held by Winslow. The conditions of deposition were evidently those of a slowly sinking shore, and the marginal deposits practically underlie the open sea formation though not necessarily much older; hence the terms lower and upper are retained, though emphasis is given to their general contemporaneity. The summary of Professor Calvin's researches on the Devonian and Cretaceous rocks shows a marked advance in the knowledge of these formations.

The classification of Iowa rocks, given by the different surveys, is here presented for comparison:

HALL'S REPORT, 1858.	WHITE'S REPORT, 1870.	CALVIN & KEYES REPORT, 1892.
Quaternary. { Alluvium. Drift.	Post Tertiary. { Alluvium. Bluff. Drift. { Altered.	Quaternary. { Alluvium. Loess. Drift. { Upper till. Lower till.
[illegible] Cretaceous. { Presence in Iowa asserted, but rocks not described. Given on Owen's authority.	Lower Cretaceous. { Inoceramus beds. Woodbury sandstone and shale. Nishnabotna sandstone.	Upper Cretaceous. { Niobrara. { Inoceramus and possibly gypsum beds, and Nishnabotna sandstone. Fort Benton. } Dakota. } { Woodbury shale, and possibly the Nishnabotna sandstone
Permian ?—Gypsum beds.		
Carboniferous. { Coal Measures. Carboniferous limestone. { Kaskaskia (not present). Ferruginous sandstone (not present). St. Louis limestone. Warsaw. Keokuk. Burlington.	Carboniferous. { Coal Measures. { Upper. Middle. Lower. Sub-Carboniferous. { Chester (not present). St. Louis. Keokuk. Burlington. Kinderhook.	Carbonoiferus. { Upper Carboniferous or Pennsylvania Series. { Missouri Stage. Des Moines Stage. Lower Carboniferous or Mississippian. { Kaskaskia (or Chester) (not present). St. Louis. Augusta { Keokuk. Burlington. Kinderhook. { Chouteau lm. Hannibal sh. Louisiana lm.
Devonian. { Chemung group. Hamilton group. Upper Helderberg limestone.	Devonian—Hamilton limestone and shale.	Devonian. { Lime Creek shale. Montpelier sandstone. Cedar Valley limestone. Independence shale.
Upper Silurian. { Le Claire limestone. Niagara limestone.	Upper Silurian—Niagara limestone.	Upper Silurian. { Le Claire limestone. Niagara limestone.
Lower Silurian. { Hudson River group. Galena limestone. Trenton limestone. Black River and Birdseye limestone. St. Peter's sandstone. Calciferous sandstone. Potsdam sandstone.	Lower Silurian. { Maquoketa. Galena. Trenton. St. Peters. Lower Magnesian. Potsdam.	Lower Silurian. { Maquoketa. Galena. Trenton. St. Peters. Oneota.
		Upper Cambrian—St. Croix.
Huronian—Sioux Quartzite—1866.	Huronian?—Sioux quartzite.	Algonkian—Sioux quartzite.

Other papers by Mr. Keyes are: "Annotated Catalogue of Minerals," and "Bibliography of Iowa Geology."

Professor Calvin's paper is devoted to the Cretaceous deposits of Plymouth and Woodbury counties. In the region studied these beds are found to be sharply divisible lithologically into two divisions, a lower consisting of soft sandstones, with bands of hard ferruginous concretionary nodules, and variegated, often parti-colored clays, the latter greatly predominating and resting upon these a white or yellowish chalk, somewhat indurated in places into a soft fissile limestone. The first is White's Woodbury sandstones and shales, and the second is his Inoceramus beds. Following Meek and Hayden, Professor Calvin makes a threefold division of the beds, by drawing a somewhat arbitrary line about forty feet below the base of the Inoceramus beds. The lowest division contains impressions of leaves and a meagre brackish water fauna. This he correlates with the Dakota group. The second or middle division of dark colored calcareous shales, containing marine mollusks, associated with the vertebræ and teeth of bony fishes, and the skeletons of marine saurians, is the Fort Benton group of Meek and Hayden. The upper or Inoceramus beds represent the Niobrara of the same authors. During this epoch the Cretaceous sea had its farthest eastward extension, probably reaching as far as the Mississippi river in northeastern Iowa.

Mr. Beyer's paper is entitled Ancient Lava Flows in the Strata of Northwestern Iowa, and relates to the discovery in a well at Hull, Sioux county, of typical quartz porphyry at a depth of 755 feet. Microscopical study shows it to have a pronounced flow structure, while the quartz crystals show the effects of magmatic corrosion, and, in some cases, fracturing with discordant orientation of the fragments, from which it is inferred that the magma was semi-viscous and under great pressure when the flow took place. In the drilling, the eruptive rock was found to alternate with sandy strata, showing evidence of metamorphism down to 1,200 feet. Two hypotheses are advanced to account for the flows: (1) That they took place in Paleozoic times, perhaps Carboniferous, the lava being periodically poured out over the old sea bottoms; and (2) that the whole series of flows was contemporaneous, and in point of time post-Carboniferous. In this case the intercalations may be regarded as intrusive sheets, following the lines of least resistance and forcing themselves between the strata. Most probability seems to attach to the latter view.

Mr. Bain's paper deals with the distribution and relations of the St. Louis limestone in Mahaska county, where it is shown to have the same irregularity as to thickness and structure as it presents generally in Iowa. To explain the irregularity in the surface of this formation, appeal is made to erosion during Kaskaskia time, when Iowa was a land surface. This would imply a considerable elevation in order to produce the carving, a conclusion not wholly free from doubt. In some localities a sandstone, treated as presumably belonging to the coal measures, rests upon the limestone.

The remaining paper, by Mr. Houser, is devoted to a discussion of some lime-burning dolomites, and dolomitic building stones from the Niagara.

C. H. GORDON.

THE

JOURNAL OF GEOLOGY

NOVEMBER-DECEMBER, 1893.

THE SUPPOSED GLACIATION OF BRAZIL.[1]

THE inquiries I have received from time to time regarding the supposed glaciation of Brazil in Pleistocene times, the doubts sometimes expressed regarding it, and the occasional appeals made to it,[2] induce me to state briefly what I know about the matter.

Strangely enough the errors of Agassiz, Hartt and Belt regarding glaciation in Brazil have been turned to account both by those who have theories that need the support they think the glaciation of Brazil would give them, and also by those who seek by means of these errors to throw discredit on the subject of glacial geology.

I believe the case has been generally dropped by geologists as not proven, but I am confident that no one wishes to ignore the evidence "merely because it runs counter to all his preconceived opinions."[3]

EARLY VIEWS OF AGASSIZ AND HARTT.

When Professor Louis Agassiz made his trip to Brazil in 1865, on board the steamer going out he gave a series of

[1] Advance quotations are made from this article by Dr. Alfred R. Wallace in Nature, Vol. 48, No. 1251, Oct. 19, 1893, 589–590.

[2] The Glacial Nightmare and the Flood, by Sir HENRY H. HOWORTH, London, 1893. MARSDEN MANSON, in the Trans. of the Geol. Soc. of Australasia, I., pt. VI., 155–170, and in the Trans. of the Tech. Soc. of the Pacific Coast, VIII., No. 2, 19. Geological and Solar Climates; their Causes and Variations, by MARSDEN MANSON, University of California, May, 1893. Ragnarok, by IGNATIUS DONELLY.

[3] WALLACE: Nature, Vol. II., 1880, 511.

lectures in which he suggested to his assistants the possibility of the South American continent having been glaciated, and reminded them that this was one of the important subjects for their investigation.[1]

I subsequently learned from Professor Hartt, who was one of the assistants, that these lectures prepared them to be convinced that glaciation had taken place in Brazil, though he himself was rather inclined to believe otherwise.

Mrs. Agassiz's book shows throughout how Professor Agassiz found on every hand, from the time he landed in Brazil till he left there, what he regarded as evidences of glacial action. In the mountains about Rio de Janeiro he found erratic boulders (pp. 86 *et seq.*); at Ereré, in the Amazon valley, he found "the only genuine erratic boulders I have seen in the whole length of the Amazon valley," (p. 418); he declared that "il n'y a pas trace des terrains tertiaires"[2] in that region, while the horizontal sediments of that valley he explained as silts thrown down in cold glacial waters behind a vast terminal moraine that stretched across the mouth of the valley (p. 426), and of which the island of Marajo was supposed to be a remnant; the table-topped hills he explained as the remnants of sediments left when this great dam broke, and the waters swept the greater part of the beds out to sea.

The lateral moraine on the south side of this great glacier he expected to find in the interior of Ceará (p. 447-8); he went to Ceará, and found at Pacatúba, near the coast, what he regarded as glacial phenomena "as legible as any of the valleys of Maine,

[1] A Journey to Brazil, by Professor and Mrs. LOUIS AGASSIZ, Boston, 1868, 15. In Mrs. AGASSIZ'S Life and Correspondence of Louis Agassiz, Boston, 1886, II., 633, it is further stated that Agassiz was confirmed "in his preconceived belief that the glacial period could not have been less than cosmic in its influence."

[2] Bul. de la Soc. Géologique de France, XXIV., 110. In a letter to Élie de Beaumont, he speaks of these beds as loess, but he gives no specific explanation of their formation. Comptes Rendus de l'Acad. des Sciences, 1867, 1269. Professor Agassiz first published his paper on the Physical History of the Amazon valley in the Atlantic Monthly for July and August, 1866; it was also published subsequently in his Geological Sketches, sec. ser. Boston, 1886. II., 153 *et seq.*, and in the Journey to Brazil.

or in those of the valleys of Cumberland in England" (pp. 456, 463).

Naturally enough these views were received in the scientific world with incredulity. As Mr. Wallace remarks, "Prof. Agassiz was thought to be glacier-mad,"[1] but his earlier observations on glaciers had been received with quite as much doubt,[2] so that the doubts have nothing to do with the case one way or the other.

Professor Chas. Fred. Hartt states in his book[3] that he was at first very skeptical about Brazilian glaciation, but that he was finally obliged to yield to the evidence collected by himself, and to confess that Agassiz was right.

It should perhaps be mentioned here, that there is a general impression that when Hartt wrote his book on the geology of Brazil, he had spent several years, and traveled widely in that country, and that the conclusions given by him are the results of all his Brazilian work. This is far from being the case. When he wrote the Geology and Physical Geography of Brazil, he had spent only a year and a half in that country; on his first trip he arrived at Rio de Janeiro, April 23, 1865, and left it on July of the following year;[4] on his second trip, he reached Pará, July 11, 1867,[5] and returned from Rio in September of that year,[6] making in all not more than eighteen months spent in that country up to the time his book went to press. The belief in the glaciation of Brazil, as there expressed, is therefore based upon his earliest and least trustworthy work in that region. Hartt fully recognized this afterwards, and I have often heard him say, "I wish I had known as much about geology when I wrote that book as I know now."

He subsequently made several trips to Brazil; in one to the

[1] Nature, II., 511. LYELL's Principles of Geology, New York, 1889, 1, 466.

[2] Bul. de la Soc. Géol. de France, 1867-8, XXV., 685.

[3] Geology and Physical Geography of Brazil, Boston, 1873, 29.

[4] Agassiz, Journey, 46 and 540.

[5] American Naturalist, I., 648.

[6] Geology and Physical Geography, 201.

Amazon valley he examined the table-topped hills[1] which Agassiz had referred to glacial action, and the boulders he had called "the only genuine erratic boulders" he had seen in the Amazon valley. Already, in 1867, Professor James Orton, who scouts the idea of the glaciation of the Amazonas, had discovered at Pebas, in the supposed glacial sediments, "marine or perhaps rather brackish water Tertiary fossils."[2]

In 1871 Hartt found the supposed erratics of the Amazon valley to be boulders of decomposition derived from trap dikes near at hand, and stated that he "did not see, either at Ereré or in any part of the Amazonas, anything that would suggest glaciation."[3] He still clung, however, to the idea that the highland of Brazil to the south had been glaciated.[4]

Unfortunately Hartt has left no further record of his later views upon this subject, but that his views underwent a radical change I know as positively as one can know the opinions of another person. I went with him to Brazil in 1874, was with him in his work there until his death in 1877, and remained yet five years later—in all eight years in that country. Under his direction I did more or less work in the mountains about Rio de Janeiro for the purpose of sifting the evidence of glaciation in that region, and I am glad to say, in justice to the memory and scientific spirit of my former chief and friend, that long before his death he had entirely abandoned the theory of the glaciation of Brazil, whether general or local, and that the subject had ceased to receive further attention, even as a working hypothesis. So much for Hartt's opinions.

[1] Bulletin of the Buffalo Soc. of Natural History, 1874, 201.

[2] On the Valley of the Amazon, by JAMES ORTON, Proc. Am. Assoc. Adv. Sci., 1869, XVIII., 195–9; On the Evidence of a Glacial Epoch at the Equator, by JAMES ORTON, The Annals and Magazine of Natural History, 1871, VIII., 297–305.

The Andes and the Amazon, by JAMES ORTON, N. Y., 1876, 282, 560. The fossils collected by Orton are described in the Amer. Jour. Conchology, IV., 197, and VI., 192. Others are described from similar places in the Quar. Jour. Geol. Soc., XXXV., 76–88, and 763 *et seq.*

[3] Amer. Jour. Sci., 1871, 295.

[4] Ann. Rep. of the Amer. Geographical Soc. of N. Y., for the year 1870-1, 252.

Thomas Belt, the author of The Naturalist in Nicaragua, says in that volume[1] that though no ice marks are visible he has seen "near Pernambuco, and in the Province of Maranham, in Brazil, a great drift deposit that I believe to be of glacial origin."

I have seen and studied the deposits to which Belt refers; my opinion is that while they bear a certain resemblance to glacial drift they are entirely devoid of positive evidence of glacial origin. The method of their formation is explained in another part of this paper.[2]

AGASSIZ'S CHANGE OF VIEWS.

It is appropriate that I here quote from Professor N. S. Shaler, a former pupil of Professor Agassiz:[3]

"There has been a good deal of discussion concerning the former existence of glaciers in the valley of the Amazon. Agassiz, to whom we owe the first suggestion of the value of glaciation as a great geological agent, at one time thought it likely that the valley of this great river had been the seat of a glacier that poured its ice from the Andes nearly down to the sea. This, which was hardly more than a suggestion put forth for the discussion of geological students, was, I believe, practically abandoned by this illustrious naturalist before his death, (In this assertion I have embodied the results of several remarks by my late master on this subject made during the last two years of his life. It is satisfactory to know that the only considerable mistake he made in the matter of glaciation was corrected by his own reflections on the subject. N. S. S.) and has been found to be an essentially mistaken view. The late Professor Hartt, geologist of Brazil, at one time thought some of the debris in the mountain districts near Rio de Janeiro was of glacial origin, but this suggestion has never been submitted to discussion, and can have no weight against the other evidence of a negative kind that goes to show that glaciation, save in higher mountain countries, has never extended into the intertropical regions."

[1] The Naturalist in Nicaragua, by Thomas Belt, F.G.S., 2d ed. London, 1888, 265.

[2] It has been asked how I reconcile Belt's statements regarding glaciation in Nicaragua with my inability to find trustworthy evidence of glaciation at a similar south latitude. I don't try to reconcile them; I am simply dealing with the facts as I know them in Brazil. I have never seen the Nicaraguan deposits, but I can't avoid suspecting that they will turn out like the Brazilian ones, J. Crawford's moraines and "moutonnéd ridges" to the contrary notwithstanding. (Proc. Amer. Assoc. Adv. Sci., XL., 265, and Science, XXII., No. 263, p. 270).

[3] Glaciers, by N. S. SHALER and W. M. DAVIS, Boston, 1881, 47.

In 1872 Agassiz went through the Straits of Magellan in charge of the natural history work of the Hassler Expedition. On that voyage he touched at Montevideo and at many points south of that place, through the straits, and along the west coast. The letters written by him on this trip suggest very strongly, if they do not conclusively show, that he had at this time already abandoned the idea that Brazil had been glaciated. Speaking of certain boulders seen by him on the Cerro at Montevideo, Mrs. Agassiz observes[1] that "As these were the most northern erratics and glaciated surfaces reported in the southern hemisphere," etc. From this it appears that he no longer regarded the Brazilian boulders as erratics.

After Agassiz had examined the glacial phenomena of the Straits of Magellan and of the southern part of the continent, he sent a report to the Superintendent of the U. S. Coast Survey, dated at Concepcion Bay, June 1, 1872.[2] This article also bears evidence that he no longer regarded Brazil as having been glaciated. In one place he says,[3] "I am prepared to maintain that *the whole southern extremity of the American continent* has been uniformly moulded by a continuous sheet of ice." The italics are mine. In the next paragraph he says, "The first unquestionable *roches moutonnées* I saw were upon the nearest coast opposite Cape Froward." Again he says (p. 271): "The equatorial limit of this ice sheet both in the northern and the southern hemisphere is part of the problem upon which we have thus far fewest facts in our possession. In South America I have now traced the facts *from the southernmost point of the continent uninterruptedly to 37 S. latitude on the Atlantic* as well as the Pacific coast." Again

[1] Louis Agassiz, his Life and Correspondence, Boston, 1886, II., 712. Rep. U. S. Coast and Geodetic Survey for 1872, 215. Nature, 1872, VI., 69. Evidently Burmeister does not regard the boulders cited as glacial, for he uses the expression, "phénomènes de glaciers chez nous, et dont nous n'avons nulle part la preuve." République Argentine, II., 214, also 392, 393. The same blocks are described by Darwin in his Geological Observations, 432. He does not seem to regard them as erratics.

[2] Published in the New York Tribune of June 26, 1872, and reproduced in Nature 1872, VI., 216, 229 and 260.

[3] Nature, 1872, VI., 230.

(p. 272) he speaks of having traced the palpable evidence of glaciation "from Montevideo on the Atlantic to Talcahuano on the Pacific coast." Speaking of evidence at Concepcion Bay he says also (p. 272) "Think of it! A characteristic surface indicating glacial action in latitude 37° S. at the level of the sea!"

These quotations show as plainly as anything short of a positive statement can that Agassiz in 1872 no longer considered as trustworthy what he had formerly regarded as the evidences of glaciation in Brazil. For if he still believed in a glacier under the equator itself, why should he tell us with exclamation points to think of a glacier thirty-seven degrees nearer the pole?

BASIS OF THE THEORY.

I should be glad to leave the matter with these statements of the changes of views on the part of both advocates of the glaciation of Brazil, but persons who have theories based to a greater or less extent on the glaciation of the tropics are very reluctant to believe, in the face of the many positive statements of both Agassiz and Hartt, and of the apparently trustworthy evidence adduced by them, that the first impressions of those excellent observers, both of whom were thoroughly familiar with glacial phenomena in the north, were altogether wrong. It is not possible, neither is it necessary, to take up here the individual cases spoken of by Agassiz and Hartt as evidence of glacial action. Very nearly all the materials referred by them to the drift fall under two principal heads:

First, the so-called erratic boulders, often imbedded in what was considered boulder-clay.

Second, transported, water-worn materials.

ORIGIN OF THE BOULDERS.

The boulders believed to be erratics are not erratics in the sense implied, though they are not always in place. The first and most common are boulders of decomposition, either rounded or subangular, left by the decay of granite or gneiss. Sometimes they are imbedded in residuary, and consequently unstrati-

fied clays, formed by the decomposition in place of the surrounding rock. And everyone has heard of the great depth to which rocks are decomposed in Brazil.[1] The true origin of these boulders and the accompanying clays is often more or less obscured by the "creep" of the materials, or, in hilly districts, by land-slides, great or small, that throw the whole mass into a confusion closely resembling that so common in the true glacial boulder-clays. In this connection too much stress can scarely be placed upon the matter of land-slides; they are very common in the hilly portions of Brazil, and, aside from profound striations and faceting, produce phenomena that, on a small scale, resemble glacial till in a very striking manner. The fact that the boulders are of various sizes, sometimes from ten to twenty feet in diameter, and have mingled with them quartz fragments derived from the veins that traverse the crystalline rocks from which they are derived, adds to the resemblance of these materials to certain glacial products. Such boulders, however, are by no means confined to the vicinity of Rio de Janeiro, but are common throughout Brazil wherever there are granites or gneisses. They have been seen by the writer in the Amazon valley (Araguary River) in the interior of Pernambuco,[2] Parahyba do Norte, Alagôas, Sergipe, Bahia, Rio de Janeiro, Minas Geraes, São Paulo, Paraná, and Matto Grosso.

The positions in which such boulders are often found are worthy of note, though one who felt disposed to regard them as transported blocks would probably not consider their positions as inconsistent with the glacial theory of their orgin. They are abundant about the bases of granite hills and mountains where they have been formed by the exfoliation of the great blocks and slabs produced by the secular decay of the hills and mountains. There are hundreds of rude boulders at the southeast base

[1] DARWIN: Geological Observations, 427; LIAIS: Climats, Géologie, etc., 2; PISSIS: Men. Hist. Inst. de France, X., 538; DERBY: Amer. Jour. Sci., 3d Ser., XXVII., 138; MILLS: Amer. Geologist, III., 351.

[2] In the American Naturalist, 1884, XVIII., 1189, I have given a sketch of some boulders found in the state of Pernambuco; see also p. 1187 of that vol.

Fig. [illegible] Boulders of Decomposition [illegible] Island of Paquetá, in the Bay of Rio de Janeiro

of the Sugar Loaf at the entrance to the harbor of Rio, at the east base of the Corcovado, and about every such mountain in the vicinity of Rio de Janeiro. They[1] rest on the summits and margins of the high, sharp mountain peaks; on the top of the Sugar Loaf at the entrance of the Rio harbor, for example, there are several such boulders, one of which is thirty feet in diameter; the top of the Gavea, the flat-topped mountain southwest of Rio, has hundreds of boulders on its summits. Agassiz mentions such boulders on the edge of rock basins (Journey, 493). He "was at a loss how to explain how loose masses of rock, descending from the heights above should be caught in the edges of these basins, instead of rolling to the bottom." The fact is that the blocks referred to originated, not in the heights above, but just where they now lie, as is shown beyond question by occasional quartz veins passing from the boulders into the rocks upon which they rest.[2]

In some of the shallow parts of the Bay of Rio de Janeiro what were once small islands have had the residuary soils removed and great nests of such boulders project from the water.[3] On the island of Paquetá in the bay are some beautiful examples of such boulders lying in the water's edge. I am fortunately able to give an illustration showing the Paquetá boulders which may be taken as a type of those found in and about the Bay of Rio de Janeiro.

The second method by which these boulders have been

[1] Sometimes boulders accumulate on one side of a hill or peak and not on the opposite side. This is well illustrated in the case of the Sugar Loaf. On the side facing the ocean there are thousands of boulders, many of them of enormous size, while on the opposite side where there is less surf there are but few. The reason for this difference is that there is a large dike-like ledge of hard rock exposed on the seaward side of the peak. This ledge does not appear on the opposite side where the mass is softer and weathers away evenly without leaving good boulder-forming fragments about the base. The ledge referred to is shown in the accompanying illustration.

[2] In SHALER and DAVIS' Glaciers, plate XXII., is given an example of boulders of decomposition in Central India. Exactly similar cases are common in the granitic and gneissic areas of Brazil.

[3] See also BURMEISTER'S Reise nach Brasilien, Berlin, 1852, 111, 112.

formed is quite similar to the first, but instead of being cores of granite or gneiss, they have been derived by the same process of exfoliation and decomposition from the angular blocks into which the dikes of diorite, diabase, or other dark colored rocks break up. Their color marks them as quite different from the surrounding granites, and the dikes themselves are almost invariably concealed. Moreover, these dikes not infrequently contain inclusions of still different rocks and we thus occasionally have boulders of various kinds of rocks mingled together. The residuary clays derived from the decomposition of these dikes are somewhat different in color from those yielded by the granites, so that when "creep" or land-slides add their confusion to the original relations of the rocks, the resemblance to true glacial boulder-clays is pretty strong. The chance of discovering the source of these boulders is further decreased by the depth to which the mass of the rock has decayed, and by the impenetrable jungles that cover the whole country and so effectually limit the range of one's observation. Dikes such as these last mentioned are not uncommon in the mountains of Rio de Janeiro. Indeed what have generally been regarded as the very best evidences of Brazilian glaciation,[1] some of the boulders near the English hotel in Tijuca, fall under this head, though some of them are of gneiss. The fact is that the great mountain masses about Rio are of granite or gneiss, while some of the boulders come from dikes or other dark-colored rock high on their sides, dikes which were not visited by Agassiz or Hartt.[2] There is a good example of a dike breaking up in boulders at the gap through which the road passes from the Jardim Botanico to the Gavea near the City of Rio. At this place the ground is covered to a

[1] A Journey to Brazil, 86 *et seq.*; AGASSIZ: Geological Sketches, Boston, 1885, II., 155 *et seq.* HARTT'S Geol. and Phys. Geog. of Brazil, 24–30.

[2] Darwin mentions boulders and dikes seen at Rio de Janeiro, (Geological Observations, pt. II., ch. XIII., 425; also Trans. Geol. Soc. London, 2d Series, 1842, VI., 427, note). Professor O. A. Derby sent Rosenbusch specimens of diabase from twelve dikes in the neighborhood of Rio de Janeiro, varying from twenty centimetres to several metres in thickness. See Dr. E. O. HOVEY'S descriptions of these rocks in Tschermak's Min. u. Petrog. Mittheilungen, 1893, XIII., 211–218.

depth of fifteen feet or more with clays through which are mingled boulders of diorite and granite and fragments of quartz. Further east, at a lower level, some of the clays have been washed over and contain subangular fragments of quartz, some of them two feet in diameter, many of which are somewhat water-worn. It is perhaps worth mentioning that these water-worn quartz fragments imbedded in clays were regarded by Hartt as the best evidence of glaciation. They were finally eliminated as such evidence near the end of a rainy season by my finding a landslide filling up a small ravine in which the bed of the stream had been strewn with similar quartz fragments, and the whole buried beneath a slide of crumpled clays. A highly instructive lesson can be had on the subject of boulders and clays, their origin and relations to the so-called drift of Brazil from Professor Derby's paper on nephelene rocks in Brazil.[1] Anyone reading that article can readily fancy how Professor Agassiz, in a flying trip across São Paulo and Minas, would have interpreted these clays and boulders of different kinds and different colors.

In regard to the so-called erratics I should mention also the opinion of another observer and writer upon Brazilian geology. Emmanuel Liais, formerly director of the Imperial Observatory at Rio de Janeiro, is very positive that there are no evidences whatever of glaciation in Brazil. Of the boulders supposed to be erratics, he says :[2]

"These boulders though numerous are always in the immediate neighborhood of the veins from which they are derived. . . . . Though presenting sometimes the appearance of erratics by their abundance and rectilinear arrangement, they are not transported boulders, and have nothing in common with erratic phenomena. . . . . I have not been able to find any signs of the existence of a boulder that can be regarded as erratic and coming from a region distant from the one where it is found. In the vicinity of these isolated boulders one always finds dikes, veins or simply masses or boulders of the same material intercalated with the terrain in place."

He speaks of the occurrence of dikes of diorite from which many of the boulders cited by Agassiz have been derived. More

[1] Quar. Jour. Geol. Soc., 1887, XLIII., 457-473.

[2] Climats, Géologie, etc., du Brésil, Paris, 1872, 18.

than a score of statements of a similar nature may be cited from Liais' book.

Count de la Hure has also pointed out how diorite breaks up into boulders, and cites in evidence some of the very cuts on the Pedro II. Railway which Agassiz and Hartt refer to the drift. Saldanha da Gama in speaking of the exfoliation and decomposition of granite rocks described by Count de la Hure and Capanema says :[1]

> "This and many other facts gathered by the Brazilian naturalist in his observations on diorite and other rocks of that class led the eminent Swiss geologist to point out that the study of the drift in Brazil will not be well understood so long as one hasn't a thorough knowledge of the decomposition of the rocks."

He also refers to the fact that these phenomena may be observed in several of the Brazilian provinces.

The two kinds of boulders above mentioned are common in the regions of crystalline rocks ; a third kind is found in those parts of eastern Brazil that are covered, or were formerly covered, by Tertiary sediments, namely in the State of Bahia, and thence northward to the Amazon valley. These Tertiary deposits contain beds of sandstone that are sometimes locally changed upon exposure to the hardest kind of quartzite. Most of the associated beds are friable and easily eroded, so that when the surrounding strata have been removed there are left behind a few blocks of quartzite, varying in size from a foot to four feet in diameter. These boulders are so unlike the rocks from which they have been derived and by which they are surrounded, that unless one has given special attention to the study of Tertiary sediments in that region he is liable to be much puzzled and even misled by them.[2]

ORIGIN OF THE WATER-WORN MATERIALS.

The second class of evidences by which Agassiz and Hartt were misled consisted of transported, water-worn materials.

[1] Revista do Instituto Historico do Brazil, 1866, XXIX., 421 *et seq.*

[2] See BRANNER'S Cretaceous and Tertiary Geology of the Sergipe-Alagôas Basin of Brazil. Trans. Amer. Phil. Soc., XVI., 1889, 419–421.

These materials are made up of boulders, cobbles, and gravels, sometimes assorted and sometimes having sand and clay mixed with them, and are spread far and wide, though irregularly, over all the Tertiary and Cretaceous area bordering the ocean, and extend for a long distance into the interior, and far beyond the borders of the Tertiary deposits. They were regarded by the writers in question as analogous to the water-worn materials so common in the northern drift. Had these materials been of glacial origin it is not unreasonable to expect that striated pebbles would have been found among them occasionally, but, as a matter of fact, no such marks have ever been found, though I have made the most diligent search for them. That the striæ have been obliterated by weathering agencies is out of the question, because the preservation of the water-worn and pitted faces of the pebbles shows plainly enough that striated faces would have been preserved equally well had they ever existed. The origin of these water-worn materials has already been explained elsewhere, and from that article the following quotation is made :[1]

"This formation is spread over the hills and valleys of the Sergipe-Alagôas basin and over the adjacent country in the form of a thin coating of cobblestones, pebbles and sand, sometimes loose and sometimes cemented into a pudding-stone as much as ten feet in thickness, and, when exposed, stained black by manganese. It caps the summit of the tertiary plateaux or their outliers, and it is frequently strewn along down the sides of hills and accumulated in the valleys. It is not confined to the geographic limits of the Cretaceous or Tertiary, but is found further inland and far beyond the present limits of these formations. It is everywhere more or less irregular in thickness, and nowhere can it be said to be universal or continuous. The writer has seen this material throughout Sergipe and Alagôas, in Parahyba, and as far inland as the head waters of the Rio Ipanema in the interior of the province of Pernambuco, where there is no remnant of stratified Tertiary beds. Between the lower Rio São Francisco and the frontier of the province of Alagôas, and indeed in many parts of the province of Pernambuco, this water-worn material is found mingled in bogs with the remains of extinct, gigantic mammals.

One of the marked characteristics of this post-tertiary formation is that it is much coarser inland, and grows finer as the coast is approached. The

[1] Trans. Amer. Phil. Soc., 1889, XVI., 421.

explanation of this water-worn material seems to be that the Tertiary period was closed by a depression along the present coast, which carried the beach line far inland, or that it was already there. Then followed a gradual emergence,[1] during which the whole area now covered by this widely distributed water-worn material was passed gradually through the condition of a beach, upon which the then loose, angular, surface rocks of the country were rounded and worn into the boulders, cobbles and pebbles which we now find scattered over this region. While the surf was beating upon and wearing the hard crystalline and metamorphic rocks of the interior it was unable to produce any very marked effect upon the topography of the country, but when, in the course of the land's emergence, the soft, sandy and clayey beds of the Tertiary were brought up within its reach, the work of land sculpture it was able to do was enormously increased. During the emergence of these Tertiary beds they were deeply eroded, and the mud which originally made part of them was washed seaward, and the coarser materials were concentrated upon the slowly receding beach. In some places these accumulations assume unusual proportions, as if they had been brought together by the gradual beating of waves along a beach, or had been reconcentrated by later streams."

GLACIAL TOPOGRAPHY.

Agassiz considered that the undulating outlines of the topography about Rio de Janeiro were attributable to glacial action,[2] though he recognizes the fact that nothing of glaciation was to be learned from their appearance.[3] A careful study of those features, made with this suggestion in mind, shows that the rounded hillsides have no uniformity in their arrangement, that is, what would be *stoss* sides, judging from the topographic forms, face now in one direction, and now in another, and that the outlines are simply those produced by ordinary decomposition and erosion, though much influenced by structural features. Hartt's opinion, as originally expressed in his book (p. 33), was that the forms of the hills were "due primarily to subaërial denudation."

THE ABSENCE OF STRIÆ.

A bit of negative evidence of great importance against the glacial hypothesis is the fact that nowhere has there been found

[1] See also Pissis in Comptes Rendus de l' Acad. des Sci., 1842, XIV., 1046.

[2] Geological Sketches, II., 157. Bul. de la Soc. Géol. de France, 1867–8, XXV., 687.

[3] Journey, pp. 69–70.

a single scratch either upon the rocks in place or upon a boulder, cobble, or pebble, that could, by any legitimate stretch of the imagination, be attributed to glacial action. And it is but just to recall the fact that both Agassiz and Hartt recognized this as the one piece of evidence, above all others, lacking for their Brazilian glacial theory. How diligently Agassiz searched for such evidence one can judge from the story of his journey as told by Mrs. Agassiz and himself, and I know that Hartt left no stone unturned and no locality unexplored that he thought might afford him the long-sought striæ. They both explained the absence of such marks by supposing that they had been obliterated by the decomposition of the rocks, and Agassiz believed that in the Amazon region there were no rock surfaces exposed.[1] But it cannot be considered credible that glacial striæ should have been preserved in Asia, Africa and Australia since Carboniferous times,[2] but entirely obliterated in Brazil, both from the bed rocks and from the conglomerates deposited in post-tertiary times, or as has already been mentioned, that the pitted and water-worn faces should have been preserved in these materials while the ice marks should have been obliterated.

James E. Mills, a professional geologist and a former pupil of Agassiz at Harvard, spent nearly two years in Brazil in the states of Rio Grande do Sul, Rio de Janeiro, and Minas Geraes. He expresses his views of the subject of glaciation in that country as follows:[3] "In those portions of Brazil which came within my field of observation there is no glacial drift, and there are no glaciated rock surfaces or glacial topography or other signs of the existence of glaciers."

Agassiz points out the weakness of his own theory regarding Brazilian glaciation very nicely in his letter to Professor Pierce,

[1] Journey, 426. There are plenty of rock surfaces in the Casaquiari region, on the Araguary, the Tocantins, the Tapajos and in hundreds of other places away from the immediate alluvial plain of the Amazon.

[2] Geological Magazine, 1886, 492–495. For the literature of the subject see C. D. WHITE in Amer. Geologist, May, 1889, 299–330.

[3] American Geologist, III., 361.

of Harvard, by saying: "But I have not yet seen a trace of glacial action proper, if polished surfaces and scratches and furrows are especially to be considered as such."[1]

BIOLOGICAL EVIDENCE.

Thus far I have confined myself to a statement of the facts that relate directly to glaciation. Aside from these a matter of the utmost importance is the continuity of life from Tertiary times down to the present, especially in the tropical and subtropical parts of the earth. If glaciation had been cosmic, as suggested by Agassiz—if it had taken place under the very equator—then the reasoning of biologists regarding the origin and distribution of the present life of the globe is about all at fault. A reviewer of Hartt's Geology of Brazil long ago called attention to the fact that "the grand objection to the theory of the former existence of a continental glacier in tropical America, is the unbroken continuity of tropical life since the close of the Tertiary period."[2] Mr. Wallace, in an earlier review, had already called attention to the same point,[3] while still another lays stress upon the important fact that the plants found in the Amazonian silts, supposed by Agassiz to be of glacial origin, are the remains of tropical plants, and are not therefore comparable with the Alpine plants growing beside existing glaciers in mountainous regions.[4]

THE OPINIONS OF OBSERVERS.

The following are some of the opinions of geologists regarding the phenomena regarded by Agassiz and Hartt as glacial. These authors are quoted, not simply for the purpose of bringing the weight of authority to bear on the subject, but because they have all seen much of the geology of Brazil and are competent to have opinions worthy of consideration. Darwin, who visited Brazil in 1832 and saw something of these

[1] Journey in Brazil, 88.

[2] American Naturalist, 1871, V., 36.

[3] Nature, 1870, II., 511.

[4] The Geological Magazine, 1868, V., 458.

phenomena, stated that no true glacial boulders had been seen in the inter-tropical regions.[1] The English botanist, George Gardner, gives the correct explanation of the formation of the soils about Rio.[2] Burmeister, who traveled extensively in Brazil, is of the opinion that the facts appealed to by Agassiz in support of his glacial hypothesis for Brazil are to be explained otherwise.[3] Liais' adverse opinion has already been cited. Dr. Guilherme S. de Capanema, a Brazilian geologist, thoroughly disbelieves in the theory of Brazilian glaciation.[4] Professor James Orton's papers in which he controverts the glacial hypothesis in so far as it relates to the Amazon valley have been cited, while Hartt himself recognized the mistake of Agassiz in that region.[5] Mr. James E. Mills saw some of the best examples of the supposed glaciation at Rio de Janeiro and spent more than a year in the highlands of Brazil; his opinion regarding what he saw has already been quoted. Professor Derby in speaking of the possibility of glaciaation omits all reference to the phenomena upon which Agassiz and Hartt placed so much stress, namely, those in the mountains about Rio, though to my knowledge, he is perfectly familiar with those phenomena.[6]

[1] Trans. Geol. Soc. London, 1842, 2nd Ser. VI., 427.

[2] Jour. Roy. Hort. Soc., 1846, p. 191.

[3] Description Physique de la République Argentine par Dr. H. Burmeister, Paris, 1876, II., 393.

[4] Decomposição dos penedos do Brazil, Rio de Janeiro, 1866; Revista do Instituto Historico do Brazil, 1866, XXIX., 421.

[5] Am. Jour. Sci., 1871, 295.

[6] In the following references more or less doubt is expressed regarding the glaciation of Brazil:

The Highlands of Brazil, by RICHARD F. BURTON, London, 1869, I., 39, II., 218. The Amazon and Madeira Rivers, by FRANZ KELLER, New York, 1874, 47. Fifteen Thousand Miles on the Amazon, by BROWN and LIDSTONE, London, 1878, 42. Brazil, the Amazon and the Coast, by HERBERT H. SMITH, New York, 1879, 634. Glaciers, by SHALER and DAVIS, Boston, 1881, 47. A Geographia Physica do Brazil por J. E. WAPPEUS, Rio de Janeiro, 1884, 55. Pre-historic America, by the MARQUIS DE NADAILLAC, edited by W. H. DALL, London, 1885, 18, foot note. Report on Coffee Culture, by C. F. VAN DELDEN LARENE, London, 1885, 24. Le Pays des Amazones par F. J. de SANTA-ANA NERY, Paris, 1885, 36. A Year in Brazil, by H. C. DENT,

I may sum up my own views with the statement that I did not see, during eight years of travel and geological observations that extended from the Amazon valley and the coast through the highlands of Brazil and to the head waters of the Paraguay and the Tapajos, a single phenomenon in the way of boulders, gravels, clays, soils, surfaces or topography, that could be attributed to glaciation. A glacial origin for certain gravels has probably been suggested by Derby,[1] because their origin is somewhat obscure, but I am of the opinion that they admit of the same explanation as the high river gravels of the southwestern United States, and that glaciation had nothing whatever to do with them.[2]

JOHN C. BRANNER.

London, 1886, 424. Three Thousand Miles through Brazil, by J. W. Wells, London, 1886, II, 373–4. Sparks from a Geologist's Hammer, by ALEXANDER WINCHELL, Chicago, 1887, 180. Notes of a Naturalist in South America, by JOHN BELL, London, 1887, 313–318 and 342. Darwinism, by ALFRED R. WALLACE, London, 1889, 370.

[1] WAPPEUS' Geographia Physica do Brazil, p. 55.

[2] It may have some value as corroborating an opinion formed before studying the geology of the Southern United States, that all the phenomena brought forward in support of the glaciation of Brazil are repeated in the Southern States, far south of what geologists readily recognize as the utmost limits of glacial ice. In Arkansas for example, boulders occur near Little Rock, of such shape, character, and distribution as to strongly suggest a glacial boulder train, if the glaciation of the region were admissible, or another explanation were not evidently the correct one. For an illustration of such boulders see Annual Rep. Geol. Survey of Arkansas for 1890, II., 25.

CAUSES OF MAGMATIC DIFFERENTIATION.

In petrographical literature in recent years attention has repeatedly been drawn to the fact, that igneous rocks, which are closely connected geographically and in age, are also chemically related to one another, showing a certain "consanguinity"—to use Iddings'[1] very fitting expression—a relationship which makes them form a distinct "petrographical province" (Judd) when compared with igneous rocks of other parts of the world. The cause of this relationship has been sought in the supposition, that all the different rocks of the "petrographical province" come from the differentiation of one common magma, originally homogeneous.

As to the manner in which the differentiation took place, opinions are divided. We may suppose that it took place during the consolidation of the magma; in this way, a part of the minerals crystallized out, then were mechanically accumulated and finally reliquified. The differentiation of the original magma into partial magmas could take place in this way, but, as far as I can see, only on a small scale. A silicate magma during its period of crystallization is certainly too viscous to permit of any considerable diffusion. For example, in the reproduction of rocks after the method of Fouqué and Lévy, in which process a glass is first made having the desired composition, this glass may be completely devitrified (fused), while it remains so viscous that pieces of it neither change form nor adhere to one another.

Another theory, namely, that the differentiation has taken place in the magma while quite fluid, possesses greater probability and therefore more adherents. But concerning the details of the method opinions differ. While certain petrographers apply the

[1] "Origin of Igneous Rocks." Bull. Phil. Soc. of Washington, 12. 89–214. (1892). This paper contains an extensive bibliography of this subject, to which the reader is referred.

laws of dilute solutions to explain the differentiation of the molten silicate magmas, others look upon the separation of the original magma into partial magmas as evidence of the incapacity of the chemical compounds, constituting the original magma, to dissolve one another completely at all states of temperature and pressure. This latter theory is not as yet very much developed, but has been considered by Durocher and Rosenbusch, whereas the first theory, which consists essentially in the application of what Teall has termed "Soret's principle," has been used by several authors, in greatest detail by Vogt.

The principle known in petrographical literature as "Soret's principle" can be correctly formulated thus: "If in the same dilute solution, the temperature is different in different places, the concentration varies also and in such a manner, that, when equilibrium is established in every point, it is universally proportional to the absolute temperature"—for, the osmotic pressure is proportional to the absolute temperature, and if the pressure is augmented in one place, part of the molecules must be driven over to the place with less osmotic pressure, in order to maintain the equilibrium. Here, as in the other applications of the laws of gases to solutions, it must be remembered that these laws apply rigidly only to very dilute solutions; concerning the behavior of concentrated solutions we know very little, and especially with reference to "Soret's principle." Further, if two or more substances are contained in the solution a difference of temperature could not change the *relative* concentration any more than it could change the composition of a gas-mixture.[1] The only thing that is altered is the proportion between the solvent and the substance dissolved.

Consequently such definitions of "Soret's principle" as "The compound or compounds with which the solution is nearly saturated tend to accumulate in the colder parts,"[2] and "The most

[1] In very concentrated solutions it might happen that the osmotic pressure is a different function of the temperature for the different substances in solution, and then the relative concentration would be changed.

[2] TEALL: "British Petrography," 394. (London, 1888). ZIRKEL: "Lehrbuch der Petrographie," Vol. I., 779. (Leipzig, 1893).

difficultly soluble compounds diffuse towards the plane of cooling"[1] are misconceptions. It is the proportion between the solvent and the dissolved substance which is changed and this is all—so far as we know at present. Consequently, in order that one may use "Soret's principle" for the purposes of theoretical petrography it is quite necessary to have the question settled: what is "the solvent" and what "the thing dissolved?"

Vogt[2] avoids this difficulty in the following way. He says: "Owing to chemical action certain 'liquid-molecules' are individualized, which are preliminarily kept dissolved in the resting magma, and which only by a subsequent lowering of temperature, or pressure, are separated in the solid condition. The minerals which crystallize first at every stage may consequently be considered originally 'dissolved' in the remaining 'mother-liquor.'" Here we find at first the supposition, that certain compounds are "individualized"[3] in preference to others, and consequently the latter as not "individualized" form a sort of chaos. But this remainder must certainly consist also of chemical compounds. The author has perhaps thought that they should be dissociated, but it must be remembered that the free ions cannot diffuse independently of one another.

In the latter part of the quotation it is stated, that the substance which crystallizes out first when temperature sinks is to be considered as dissolved in the solvent, which crystallizes at a still lower temperature. But, in general, it is the solvent which crystallizes out first when the temperature falls, and this crystallization goes on until the "eutectic proportion" (Guthrie) is reached, when both the substance dissolved and the solvent crystallize simultaneously until the whole is solidified. If Vogt's reasoning is correct, the more a dilute solution of nitre is diluted with water, so much the more should the water be regarded as the substance dissolved.

[1] "Die am schwersten löslichen Verbindungen diffundiren nach der Abkühlungsfläche hin." BRÖGGER: Zeitschr. f. Krystallographie 16, 85. (1890).

[2] Geologiska Föreningens Förhandlingar 13. 526. (Stockholm, 1891).

[3] Or "constituted" in the German edition, Zeitschr. f. prakt. Geol., 1893, 273.

Thus I have tried to show, that "Soret's principle" cannot be applied to magmas, and consequently, if magmatic differentiation were a process of molecular diffusion it could not be explained. And it seems to me to be going too far to apply the laws of dilute solutions to magmas before having attempted to consider them simply as mixtures of liquids.

As an illustration of the conduct of two liquids when mixed, let us take aniline and water. If they are mixed at ordinary temperature, when equilibrium is established two layers are formed, one containing 1 per cent. of aniline and 99 water, the other 98 aniline and 2 water.[1] But if they are mixed at 100° the two layers formed will contain 4 aniline and 96 water, and 91 aniline and 9 water; at 150° the proportions are 14 aniline and 86 water, and 76 aniline and 24 water; at 160° they are 25 aniline, 75 water, and 68 aniline, 32 water, and at 166° the two layers should have the same composition, being consequently identical. Therefore, *above* 166° aniline and water mix in all proportions, but *below* this temperature the reciprocal dissolving capacity is limited and generally a separation into two layers takes place, the composition of which is a function of the temperature.

This seems to be common for all liquid-mixtures where no chemical action takes place. For all such mixtures there exists a temperature, above which they mix in all proportions. It is true that this temperature is known only for a few combinations of liquids, but it must be regarded as certain that it exists, and if not below then at the critical temperature, because here the capacity of mixing in all proportions is a general property of the gases.

On the other hand, there are certain fluids, which at ordinary temperature dissolve one another without limit, and for these the temperature below which the dissolving capacity is limited is yet to be determined, but in some cases this may not be reached before the transition into the solid form takes place. For us the principal question now is, can we assume that all the chemical

[1] The numbers given are obtained by interpolation in the curve of Alexejew in WIEDEMANN's Annalen 28, table 3. (1886).

compounds forming the original rock magma are completely soluble in one another? I think not.

We are told by Vogt[1] that silicates can be melted together in all proportions. This may be true, but it does not prove that this mixture would not separate into layers of different composition, or at least become heterogeneous, if it were kept molten for a sufficient time. The viscosity of molten glasses is very great and consequently the separation must take time. Still evidences of such separation—or *liquation* as we may call it, following Durocher—in the manufacture of glass are not wanting. It is well known to be very difficult to produce large pieces of homogeneous glass, for example for optical purposes. According to Wagner's Handbuch der chemischen Technologie[2] this comes from the fact, "either that the individual compounds formed during the melting process have not dissolved one another or that they have separated from the mixture by a lowering of the temperature"; and further, "One will seldom find large pieces of glass, which are completely free from this fault."[3] But it is not necessary to leave the field of geology in order to decide the question whether magmatic differentiation is a diffusion, or a liquation, process. Let us select some examples of differentiation, and examine them in the light of both theories. I have chosen two, one on a small scale, the basic inclusions, and one on a large scale, the great petrographical province of Iceland.

By diffusion, according to "Soret's principle," the basic inclusions could never be thought to have been formed in situ or approximately so—for, between them and the surrounding magma there would be no difference in temperature, or at least no difference sufficient to alter the osmotic pressure, which is proportional to the absolute temperature, or enough to produce

[1] Zeitschr. f. prakt. Geol., 1893, 272.

[2] 13th edition, 720. (Leipzig, 1889).

[3] "Entweder die einzelnen beim Schmelzprocesse entstandenen Verbindungen sich gegenseitig nicht aufgelöst, oder bei einem Nachlassen der Temperatur aus einem Gemenge sich abgeschieden haben"; and further, "Man wird selten grössere Stücke von Glas finden, welche von diesem Fehler vollkommen frei wären."

so radical a change in chemical composition. These inclusions must, by this theory, be considered to be fragments of older rocks, formed in this way. Still basic inclusions may be supposed to have been formed by mechanical agglomeration, and no doubt this has often been the case. But, in opposition to both these theories, it is in many cases evident that the inclusions were *soft*, and then the simplest view is that they were drops, or portions, of a partial magma, which at the temperature, existing immediately before crystallization, could no longer be held in solution by the principal magma, but separated out,

The great petrographical province of Iceland is characterized principally by enormous eruptions of plagioclase-basalts and exceedingly subordinate eruptions of rhyolites, which, however, are very numerous. No other eruptive rocks are known from Iceland up to this time.[1] If we considered the differentiation of the primary magma, which here was very basic, as a diffusion-phenomenon, according to "Soret's principle," it would be incomprehensible why the differentiation never stopped with the production of an intermediate magma, and, moreover, this theory would demand that every little rhyolite-magma previous to the eruptions would have been surrounded by a broad zone, showing all transitions to the basaltic magma. In both cases these intermediate magmas should have been erupted at some time, but, as already mentioned, we know a hundred eruptions of rhyolite but not a single one of andesitic rocks. It therefore seems more probable that these intermediate magmas never existed in the petrographical province of Iceland, but that the acid partial magmas were separated out directly from the basic original magma, which by lowering temperature lost its homogeneity. The conditions of temperature and pressure being different in different places these acid partial magmas also became somewhat different, but may all be classified as soda-rhyolites. The chemical compounds, which constitute the silicate magmas—and which are not necessarily identical with the rock-forming

[1] Refer to H. BÄCKSTRÖM: "Beiträge zur Kenntniss der isländischen Liparite" in Geol. Fören. Förh. 13, 667. (Stockholm, 1891).

minerals—are naturally more than two, and therefore the liquation must become very complicated, being not only a function of temperature but also dependent on the original proportions. Therefore, in other places, where the original magma had another composition, relatively stable andesitic magmas might be formed, but this was evidently not the case in Iceland.

Liquation is no doubt also a function of the pressure, but experimental data are wanting. Still it may be considered as probable that, if liquation would augment the volume of the magma, then pressure would act the same as increase in temperature, and inversely. The first is most frequently the case with liquid-mixtures.

The purpose of this communication is to give to liquation and not to diffusion its place as the working hypothesis, upon which the theory of differentiation is to be constructed. How far this theory may differ from the approximation to it, given by Rosenbusch in his "Kern"-theory, the future will show.

In conclusion, I wish to express my best thanks to my friend and colleague Dr. S. Arrhenius for much valuable information furnished me in numerous discussions on this and other subjects which lie on the border between petrology and physical chemistry.

HELGE BÄCKSTRÖM.

THE GEOLOGICAL STRUCTURE OF THE HOUSATONIC VALLEY LYING EAST OF MOUNT WASHINGTON.[1]

(With Plates V, VI, VII.)

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Conclusion.

In a former paper[2] I have discussed the geological structure of Mount Washington and shown that in that mass we have to deal with a conformable series of beds embracing four distinct lithological members. These members are: (1) a lower dolomitic limestone—the Canaan Dolomite; (2) a lower schist member containing usually abundant garnets and frequently also staurolite—the Riga Schist; (3) a calcareous member, in the valley a marble but on the summit plain of the mountain and along its base very micaceous and graphitic—the Egremont Limestone; and (4) a schist member very feldspathic and

[1] Part of a report of work done as Assistant Geologist in the Archean Division of the U. S. Geological Survey, under the direction of Professor Raphael Pumpelly.

[2] On the Geological Structure of the Mount Washington Mass in the Taconic Range. Journal of Geology, Vol. I., p. 717.

usually either chloritic or sericitic, but always free from garnets and staurolite—the Everett Schist.

The area studied.—To the eastward of Mt. Washington, at a distance of five or six miles, flows the Housatonic river, its general course being like the crest-line of the mountain, nearly south. To the northeastward of the mountain the intervening area is a nearly level plain in which are extensive outcrops of the Egremont Limestone, sometimes with thin intercalated micaceous or quartzitic layers. This limestone belt extends almost to the river at Great Barrington and Sheffield Plain. South of the village of Sheffield, however, the level expanse of the plain is broken by the occurrence along its eastern margin of low, sharp ridges trending northeasterly to northwesterly, and increasing in number as well as in height and breadth in going south. The area covered by these ridges begins at Sheffield where two narrow ridges are separated by only a few hundred feet, and broadens steadily in going southward, thus narrowing the belt of limestone on its western border, and finally cutting it off near the village of Salisbury by making connection with the southeastern base of Mt. Washington. (Cf. Plate III. of Mt. Washington paper). Corresponding with the increase in breadth which characterizes the area in its southern portion, there is a marked increase both in the height and the width of the individual ridges. East of the Twin Lakes in Salisbury is Tom's Hill, which rises to a height of over 1,200 feet, while further south, to the east of the village of Salisbury, is Barack M'Teth (1,300 feet), and Watawanchu Mountain (1,300 feet), and farther east in about the latitude of Watawanchu Mountain is Mt. Prospect[1] (1,460). This tongue of alternating schist ridges so sharply outlined, presents so much of unity in topographical and geological features as to be eminently suited to separate treatment. As the ridges are composed of the Riga and Everett Schists, the area is closely connected geologically with Mt. Washington. This paper is devoted to the consideration of

[1] To be distinguished from one of the northwest peaks of Mt. Washington which bears the same name.

the structure within this tongue-like area, which includes between twenty and twenty-five square miles. The field work was mainly done in 1888, though the southern portion of the area was revisited in 1891, when the writer was assisted by Mr. Louis Kahlenberg, and again in 1892 when he was assisted by Mr. H. J. Harris. The work has been in charge of Professor Pumpelly, then the head of the Archean Division of the U. S. Geological Survey.

Views of Percival and Dana regarding the area.—Though the map accompanying Percival's report does not indicate the schist areas within the area which is under consideration, he several times mentions them in the text. One is surprised to find how accurate were his observations and how correct his views regarding the area, notwithstanding the limited facilities and unsatisfactory condition of his survey. The following extracts from his report[1] contain the more important statements which he made having reference to this area.

"It (the limestone) is accompanied throughout with Mica Slate sometimes forming thin interposed beds, and at other times extensive ranges. The Mica Slate, in the vicinity of the limestone, particularly when interposed in thin layers in the beds of the latter, is very generally dark and plumbaginous, but occasionally light gray, as in the more extended ranges. These latter usually occupy high narrow abrupt ridges, sometimes quite isolated, and at other times in longer ranges, generally with an irregular outline." (Pp. 126–127).

"A coarse dark Mica Slate, veined or knotted with quartz, and often abounding in staurotides and garnets, occurs especially in the north part of the ridge bounding, on the west, the valley south of Lime Rock village, ..." (P. 127).

"The general surface of the valley, in the north part of Salisbury, in Canaan, and in the adjoining part of Massachusetts, is low and level, but traversed by ridges of Mica Slate, often high and abrupt, either isolated, or in long continuous ranges, the latter generally presenting a distinctly curved outline." (P. 129).

"Between these two branches[2] extends a series of Mica Slate ridges, continued north from the ridge bounding the valley at Weed's Quarry (Kl.) on

[1] Report on the Geology of Connecticut, by JAMES G. PERCIVAL, New Haven, 1842, pp. 124–130.

[2] Of the Housatonic Valley.

the west, in a very undulating course, and marked by several transverse depressions, to a high isolated summit,[1] adjoining the north line of the east of the North Ponds[2] (Salisbury)." (P. 129).

In a paper read before the American Association in 1873[3] Professor J. D. Dana quotes Percival as stating that the mica schist in which he found garnets in the township of Salisbury, is below the "Stockbridge or Canaan Limestone," but giving it as his own view that the schist is the overlying rock. This observation of Percival has considerable interest, for though the "Stockbridge or Canaan Limestone" has been shown to consist of two members, one of which is below and the other above the Staurolite-bearing rock, it is probable that Percival discovered a locality at which the Riga Schist comes out from below the Egremont Limestone.

On the map accompanying Professor Dana's paper entitled Taconic Rocks and Stratigraphy,[4] a number of schist areas are represented within the area here treated, which he correctly described to be, in some cases at least, "isolated within the limestone area, — as isolated as islands in a sea."[5] He mentions eleven of them in Salisbury and eight in the part of Sheffield township just north. He believed that there is but one schist horizon, which overlies the limestone, and described three localities, nearly or quite within the area studied, to sustain his views. These are, (1) the hill three miles north of Gallows Hill (locality 4, l. c., p. 213) where the schist "overlies the limestone"; (2) Turnip Rock (locality 5, l. c., p. 213) where schist overlies limestone in a shallow synclinal; and (3) Tom's Hill in Salisbury, which is described as a very flat trough of schist toward the north, but developing farther south into an overturned synclinal with its axis dipping east (l. c., p. 214). The observations made by

[1] Tom's Hill.

[2] Twin Lakes.

[3] On Staurolite Crystals and Green Mountain Gneisses of the Silurian Age, by J. D. Dana. Proc. A. A. A. S., 22d (Portland) Meeting, 1875, p. B25.

[4] American Journal of Science, Vol. XXIX., June, 1885.

[5] Amer. Jour. Sci., Vol. XXIX., March, 1885, p. 211.

the writer accord with those of Professor Dana in the second instance only, which relates to the upper or Everett schist member. As will be fully shown below, the other mentioned localities have a much more complicated structure than was supposed by Professor Dana.

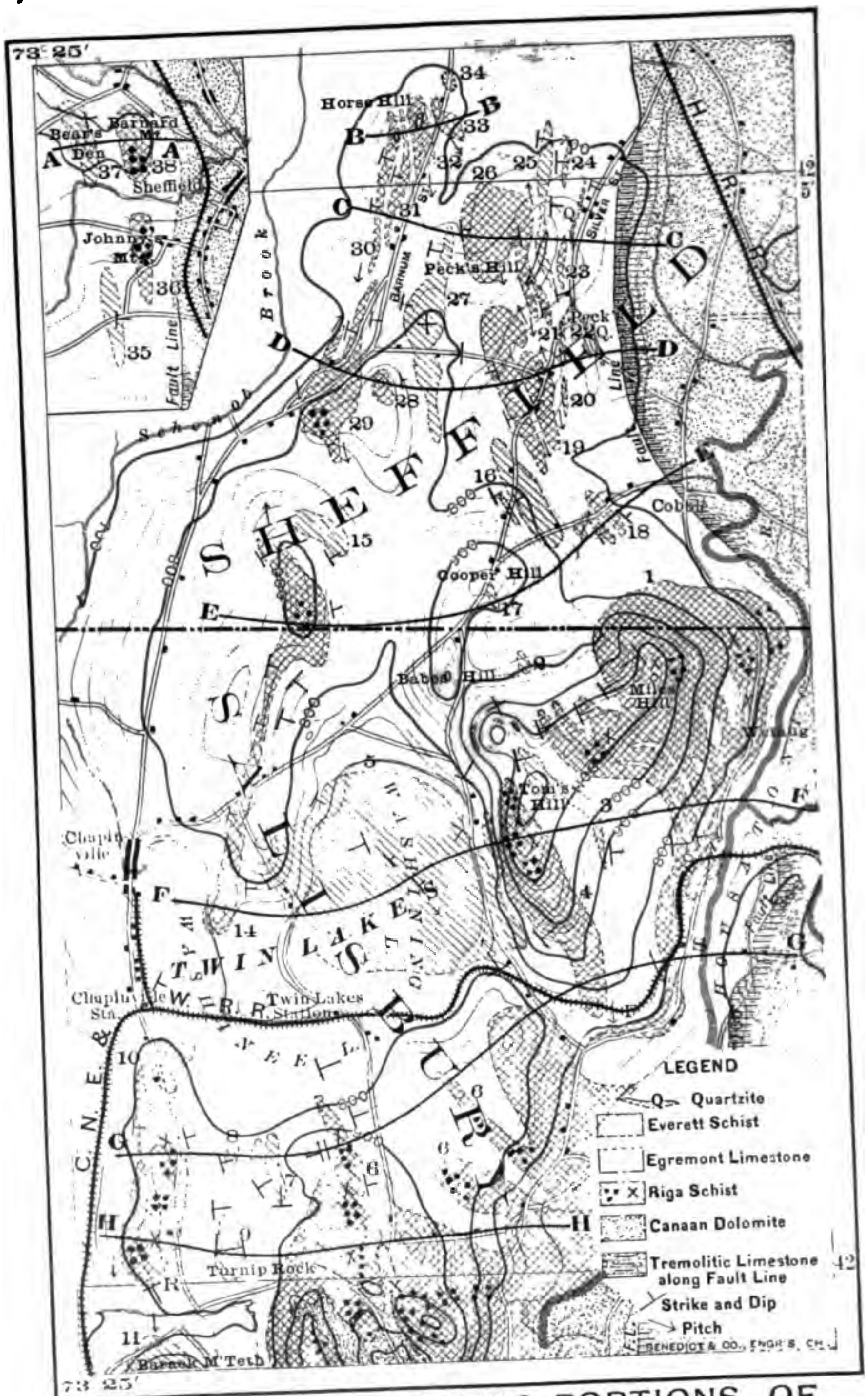
LITHOLOGICAL CHARACTERS OF THE HORIZONS.

As has already been stated, the horizons outcropping within this area all belong to the Mt. Washington series, viz.: The Canaan Dolomite, the Riga Schist, the Egremont Limestone, and the Everett Schist. The Canaan Dolmite seems to be for the most part a dolomite or dolomitic limestone, with more or less admixed quartz. A white pyroxene or salite is found to be common in it in the vicinity of Canaan, and in the belts extending east and northeast from that point. It has also been found at several localities in the vicinity of Lime Rock, but is only rarely seen west and southwest of that place. Tremolite is also found in this horizon, but as will be more fully explained beyond, this is largely restricted to a zone bordering the Housatonic River on the east. Masses of Canaanite are also found in this horizon, and as neither pyroxene nor tremolite has been found in the Egremont Limestone, their presence here is useful for purposes of identification.

The Riga Schist within this area has the characters which distinguish it on Mount Washington. In most of the ridges where it occurs, garnets alone or garnets and staurolites have been found in it. They are most abundant and of largest dimensions in the ridge south of Twin Lakes Station, the ridge south of Chapinville Station, in Tom's Hill and Mile's Hill, in Mt. Prospect (south of the area here mapped), and in Barnard Mt. and Johnny's Mt.[1] near Sheffield.[2] The mica is often a silvery

[1] These minerals were described from this locality in 1824 by Dr. Chester Dewey. Am. Journ. Sci., Vol. VIII., p. 7.

[2] Professor Dana has specially mentioned them from many of these localities. (l. c., p. 440). The increase in size of garnets and staurolite from Mt. Washington to the Housatonic, as described by him, has not been confirmed by this study. The largest that have been noted are from the south end of the ridge south of Chapinville Station.



GEOLOGICAL MAP OF PORTIONS OF SHEFFIELD, MASS. AND SALISBURY, CT.

One Mile

sericite and considerable graphite is sometimes associated with it.

The Egremont Limestone resembles that found along the east base of Mt. Washington, its principal impurities being muscovite and quartz. It contains locally important layers of calcareous mica schist. In the vicinity of Twin Lakes, two distinct beds of the latter are made out, one immediately below the Everett Schist—a transitional zone—and the other lower down near the middle of the horizon. A third, less important and less constant, zone forms a transition from the Riga Schist to the Egremont Limestone. The upper of these layers forms the cap of Babe's Hill (northeast of Washining Lake). The middle layer is also found in the same hill along the southwest base, and the lowest layer may be seen above the Riga Schist at the first road-corner northeast of Chapinville. Graphitic phases are found as a transitional zone between this horizon and the overlying Everett Schist in the northeastern part of the area, particularly in areas 16 and 25.

The Everett Schist is not chloritic to any marked degree, as is so often the case on Mt. Washington, but is frequently sericitic, usually porphyritic from rounded eyes of feldspar, and frequently passes downward into graphitic schist.

EXPLANATION OF MAP.

The map which accompanies this paper (Plate V.) is based on the Sheffield and Cornwall sheets of the topographical atlas of the United States, by the U. S. Geological Survey, and is drawn on the same scale—1 : 62,500, or one inch to the mile. It overlaps by about one half mile the map which accompanies the Mt. Washington paper. To bring as much of the area as possible on the page, the narrow northern portion is placed in one corner, its actual position being roughly indicated by the positions of the Housatonic Railroad and the large marsh to the west of it. Fig. 5 also extends the map some distance to the south. The area covered by the Egremont Limestone is left blank, while the Riga and Everett Schist areas are shaded, the

former being the darker. The more important of the schist areas have been given numbers from 1 to 38. An attempt has been made to indicate the geological structure on the map by the introduction of such of the important dip observations as the scale of the map will allow, as well as small arrows which indicate the inclination of the trough and crest-lines (pitch). The course of an important fault is traced along the east bank of the Housatonic River.

GEOLOGICAL STRUCTURE OF THE AREA.

Since the beginning of the study of the Green Mountains by the Archean Division of the Survey, Professor Pumpelly has emphasized the necessity of making careful observations of the pitch of flexures, in order to arrive at a complete knowledge of the geological structure. Observations of this character have furnished the key to the structure within the area here studied. The crest lines of the folds show considerable and frequently changing inclinations, but the beds have withstood the stress to which they have been subjected in this direction without dislocation, as there is no evidence of any cross faults. The disturbance which came from the east, and which developed the flexures, has been so great as to overturn most of them, so that their axes dip east, and locally to cause a disruption with the production of rather steep thrusts of small displacement. An important dislocation has occurred along the course of the Housatonic River, which has carried the Canaan Dolomite over the newer beds exposed west of the river.

Structural features as shown in longitudinal sections.—A glance at the map will show that all the important ridges, with the exception of Barack M'Teth, Turnip Rock, and the Bear's Den, are formed of the Riga Schist. The fact that these ridges steadily increase in height in going southward, as well as the tongue-shaped outline of the area, indicates that the general pitch of the flexures is toward the north. This is in perfect accord with the fact that the folds in the main part of the Mt. Washington Mass have a northerly pitch. But although the general pitch within the area now under consideration is north-

erly, the local pitch[1] varies greatly both in degree and direction, and is as frequently southerly as northerly, as indicated by the arrows on the map. At the south base of Tom's Hill the southerly pitch varies from 30° to 50°, and on the road cutting across the north foot of Barack M'Teth, beautiful corrugations in the Everett Schist pitch southward at as steep an angle as 50°. These corrugations are unsymmetrical, the west limbs being the shorter and steeper. The local variations in pitch are strikingly indicated on the map by those ridges of schist which are arranged linearly in the direction of the prevailing strike, being cut off from one another by limestone. The minor changes in pitch are further shown by variations in width of the ridges. Thus we find along the western margin of the area three marked undulations in the crest-line of an anticlinal of Riga Schist trending north-northeast. The northernmost is essentially the double undulation of Horse Hill and area No. 29, then follows the area northeast of Chapinville (14), and the area south of Chapinville Station (10). Fig. 1, which is a longitudinal section along this line, shows besides the three main undulations just mentioned, a number of secondary waves of more or less importance. In Fig. 2 (A) these curves of the crest-line may be better observed. The manner in which this anticlinal ridge disappears near the southern limit of the map is shown in Fig. 1 of Plate VII. The

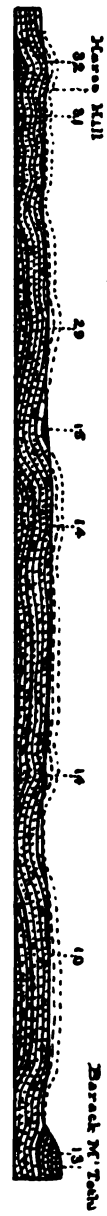


FIG. 1. Longitudinal section from Horse Hill to Barack M'Teth. Horizontal scale, one inch equals one mile; vertical scale, one-eighth inch equals five hundred feet.

[1] The pitch at any given locality is determined, either (1) by the direction in which the strike of the two limbs of a fold diverge in a synclinal fold or converge in an anticlinal fold; or (2), by the pitch of the plications in the schist. The harmony in direction and degree of inclination between the pitch of plications and that of the folds of which they are a part, was first suggested by Professor Pumpelly, and proven in the Greylock area. (Cf. T. Nelson Dale, Amer. Geologist, July, 1891).

ridge of Riga Schist is seen at A outlined from the surrounding Egremont Limestone by a dotted and dashed line. At B and C are seen Turnip Rock and Barack M'Teth, composed of Everett Schist. Between A and C the average strikes in the limestones are nearly east-west, and the dips (due entirely to pitch) about 30° south. Approaching Turnip Rock the strikes become northerly and the dips easterly, as the limestone mantles around the ridge A.

A second elevated area of the Riga Schist having three principal undulations in the direction of its prevailing strike,

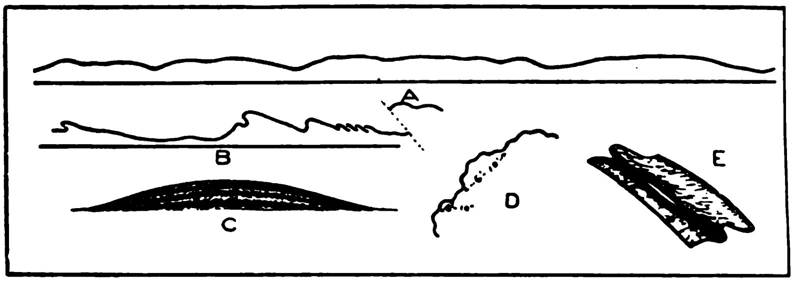
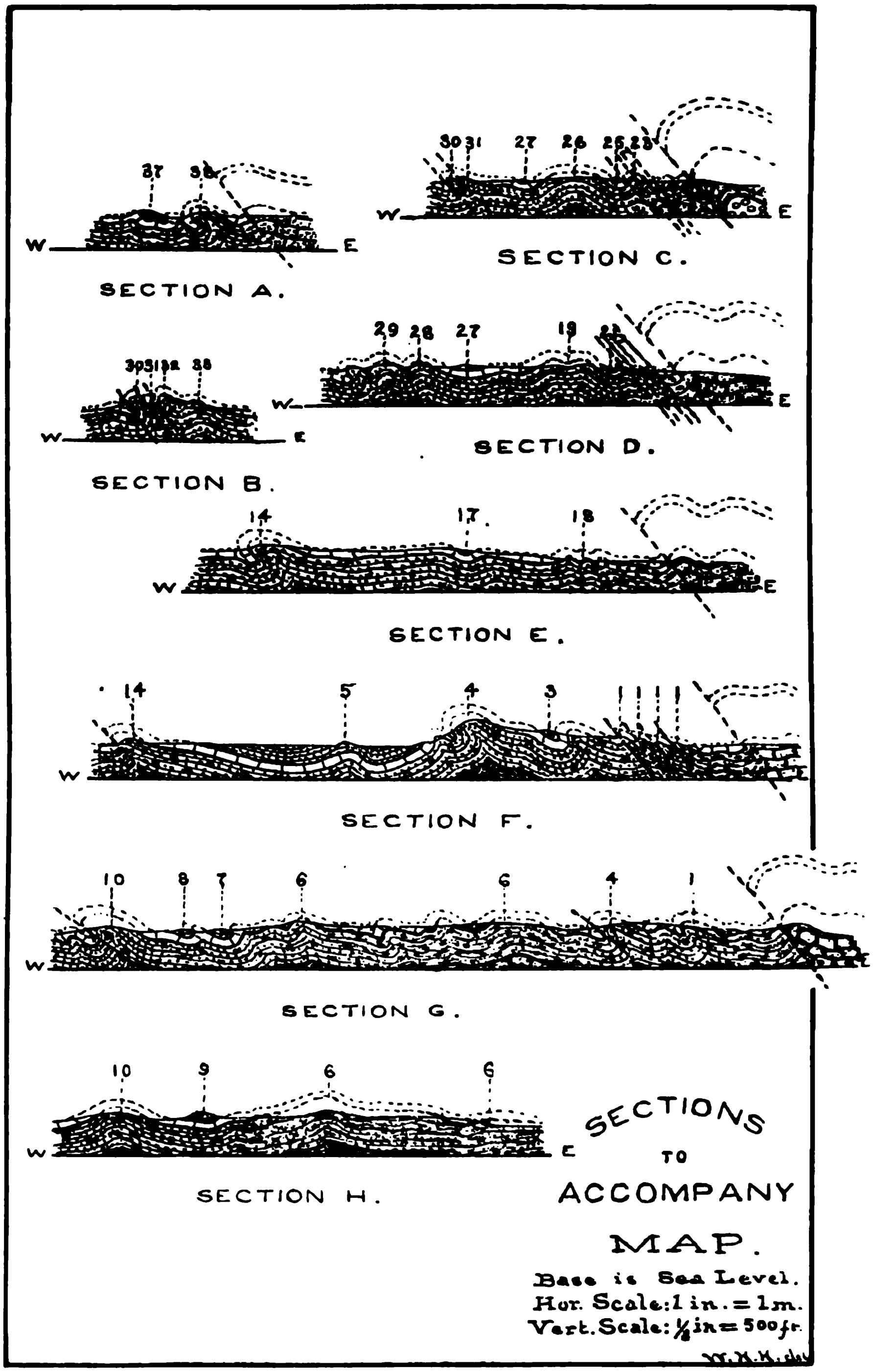


FIG. 2. Diagrams illustrating some of the structural features of the area studied. A, Flexures in crest-line of the western ridge of Riga Schist. B, Flexures in Tom's Hill and region to the west (from section F, Plate VI). C, Diagram showing the corrugated character of some of the smaller schist knolls near Salisbury. D, The same in section. E, Diagram showing the probable manner of development of small steep thrusts in the sharply folded region southeast of Tom's Hill, and in Horse and Peck's Hills.

corresponding with the three undulations of the western schist anticlinal, is traced along the eastern margin of the district. The northern of its three undulations brings to the surface in Peck's Hill, schist areas 26 and 19, and the accessory overturned and ruptured fold of areas 22–24; while the central undulation brings up in Miles Hill and Tom's Hill schist areas 1 and 4, and the southernmost undulation develops the extensive schist areas south of Washining Lake (Area No. 6). The schist of Peck's Hill disappears south of the swamp on the north base of the elevation, but the narrower eastern fold reappears north of the swamp in Johnny's Mount and Barnard Mount, where it, too, soon disap-


SECTION A.
SECTION B.
SECTION C.
SECTION D.
SECTION E.
SECTION F.
SECTION G.
SECTION H.
SECTIONS TO ACCOMPANY MAP.
Base is Sea Level.
Hor. Scale: 1 in. = 1 m.
Vert. Scale: ⅛ in. = 500 ft.

pears beneath the limestone as the most northerly outcrop of the Riga Schist. The southern limit of the central crest of the eastern undulation is at the south base of Tom's Hill, where the schist disappears through a southerly pitch varying from 35° to 50°, allowing the Housatonic River to take at this point a south-south-westerly course after being carried to the eastward by the unyielding schist mass of the hill. The minor undulations of the crest-lines of flexures within the northern part of this eastern ridge, are beautifully shown, not only by the areal relations and by divergence of strike observations, but also by the pitch of the plications (cf. arrows on map). Within the central undulation (Miles Hill), the same feature is indicated in the small basins of limestone which are entirely enclosed within the boundaries of the Riga Schist. The triple undulation of the western ridge of the district has a perfect parallel on the east. To the southwest of Tom's Hill just south of Washinee Lake appears an anticlinal of schist, which continues to rise and broaden in going south. The island in the lake is an anticlinal of the Egremont Limestone where it mantles over the ridge of schist. From below the schist anticlinal emerges the Canaan Dolomite near the southern margin of the map. As would be expected, the caps of Everett Schist which are found within the area studied, are widest opposite where the ridges of Riga Schist disappear, *i. e.*, where basins of quaquaversal synclinals are formed by the coincidence of longitudinal and transverse synclinals.

Structural Features as shown in transverse sections.—The nature of the flexuring within the area studied is indicated in the series of sections (cf. Plate VI). The types are the unsymmetrical fold with shorter and steeper western limb, indicating an easterly dipping axis, and the overturned or reversed fold with easterly dipping axis less steep than the first. The western limb of the sharper reversed folds has been ruptured, in some cases producing rather steep thrusts of small displacement. The hade of these faults is about 45°. The main flexures carry also subordinate systems of flexures. The areal geology of Horse Hill and Miles Hill in particular, shows that these properly secondary foldings

are corrugated by a tertiary system of small flexures, and examination of the plications at localities usually reveals even a quarternary system of minor foldings. Many of the small knolls near Salisbury present a surface something like the half of a muskmelon, except that a section, instead of resembling an epicycloid, would be more like a sine curve developed on an arc (cf. Fig. 2 (C). Figure 2 (D) illustrates this structure as seen in the anticlinal ridge No. 6 south of Twin Lakes Station, and in a number of small hills near Salisbury.

The Everett Schist occurs in caps or mantles which are for the most part shallow, nearly symmetrical, synclinals, as exhibited

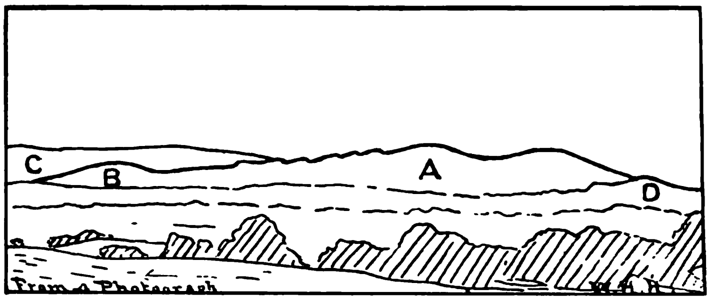


FIG. 3. View of Tom's Hill from the northwest, showing the serrated contour caused by the alternation of belts of schist and limestone. A, Tom's Hill. B, Northeast foot of Miles Hill. C, Canaan Mt. D, Babe's Hill.

in Turnip Rock (9), the cap on the southwest slope of Peck's Hill (27), and the Washining Lake Mantle (5), the latter being a double synclinal, as shown by the anticlinal ridge which forms the island in the lake.

Structure of Tom's Hill.—The doubled-peaked elevation east of Washining Lake is a compound anticlinal of Riga Schist, with two prominent crests appearing in Tom's Hill and Miles Hill respectively. These anticlinals, like most others in this region, are pushed over to the westward. A number of subordinate anticlinals, likewise compressed and overturned and here probably ruptured, are indicated on the map along the northern boundary of the Riga Schist by fingers of schist which protrude

FIG. 1.

FIG. 2.

FIG. 3.

into the limestone, as well as by the serrated contour of the ridge when seen from the northwest (cf. Fig. 3). Between Tom's Hill and Miles Hill is a fold of Egremont Limestone overturned to the west and enclosing a core of the Everett Schist. The islands of limestone inclosed in the schist of the eastern flank of Miles Hill, are the result of frequent alternations of pitch in small reversed folds which for a short distance have been ruptured. A stereogram showing the surface of the schist before it had been cut away by erosion would here present the characters of a choppy sea (cf. Fig. 2 E.) These long alternating belts of schist and limestone on the southeast foot of the hill northwest of the railroad bridge (V on map), are indicated topographically by a series of low, sharp ridges which have gradual east and steep west slopes (cf. Plate VII., Fig. 2). Farther south, near the railroad bridge, the several schist ridges become fused together and show more symmetrical undulations. The dips are here uniformly east at angles varying from 30° to 50°, and the closeness with which the belts are crowded together allows insufficient room for the full thickness of the Egremont limestone of this vicinity. The indications therefore are that the folds have here been so sharply compressed that the beds have found relief in a slight dislocation or thrust, producing a structure best illustrated in Fig. 2 (B), to which Suess has applied the term *Schuppenstruktur*,[1] and which I would term *weatherboard structure*. It is probable that both the throw and displacement of these dislocations is very slight, being greatest where the crest-lines show an anticlinal structure and least where they show a synclinal structure. An attempt has been made to show the nature of these dislocations as they are supposed to occur on the southeast flank of Miles Hill (Fig. 2 E.) Owing to the covering of earth in the valleys, the course of the fault is not exposed. The only locality where the beginnings of such a

[1] EDUARD SUESS: Das Antlitz der Erde, Vol. I., p. 149.

Gosselet has used *structure ecailleuse* (Ann. soc. geol. du Nord, Vol. XII., 1885, p. 197) for similar structures, and Margerie recommends *structure imbriquée* (Margerie et Heim, Les dislocations de l'ecorce terrestre, Zürich, 1888, p. 82).

fault have been actually observed in the rock exposure, is on the railroad a half mile southeast of the locality just described (S on map). The nature of the flexuring at this point is made

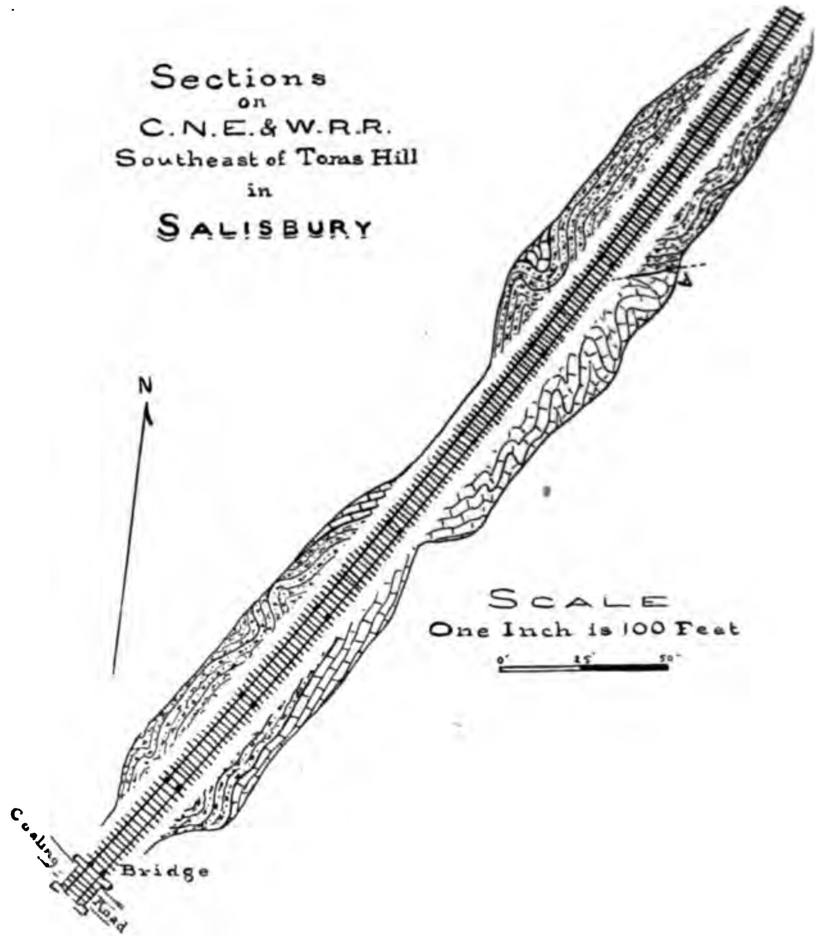


FIG. 4.

clear in Fig. 4, which shows sections in Riga Schist and Egremont Limestone both northwest and southeast of the track, developed on the plane of the track. At the point A, a sharp overturned fold in the limestone shows unconformity with the

underlying schist through a slight fault. The marked difference between the sections north and south of the track is due to steep southerly pitch.

The great Housatonic Fault.—Enough has been presented in the Mt. Washington paper and in the present discussion, to show that the limestone of this region is divisible into two horizons—the Canaan Limestone or Dolomite, lower than the Riga Schist, and the Egremont Limestone above that schist. Additional evidence might be brought forward, if it were necessary, from the region lying to the southward in the vicinity of Limerock. As has also been stated, the Canaan Dolomite, particularly in the vicinity of Canaan and in the valleys east and northeast of there (Monterey, Mill River, Clayton, East Canaan), abounds in crystals of white pyroxene, which has never as yet been found in the Egremont Limestone. Hence this mineral has a certain value for purposes of identification, comparable with that of the garnet and staurolite of the Riga Schist. Masses of Canaanite also occur in it though absent from the Egremont Limestone. Early in this investigation, when the possibility of a differentiation of the limestone was only suspected, this lithological peculiarity was noted, but as the pyroxene-bearing limestone to the eastward did not seem to be separated from the pyroxene-free limestone to the westward by any areal break, the question of divisibility was left open. It was, however, observed that the Housatonic river roughly outlined the westward extension of the pyroxene-Canaanite rock to the north of the interstate boundary. Another striking feature of this line is a ridge more or less pronounced, having its course along the banks of the river. In the southern half it follows the east bank of the river, but crosses it at the small hill called the "Cobble," just northeast of Miles Hill, and to the north of that point borders the west bank.[1] This ridge is composed of a rock which has not been found elsewhere in the region. It is a dolomite abounding in tremolite and containing layers of quartzite and quartzitic dolomite. Par-

[1] The southern portion of this ridge (that east of the river) is the ridge mentioned as Canaanite on page 126 of Percival's report.

ticularly along its west margin the rock is found to be seamed with vein quartz in every direction. These characters have not been found outside of the ridge, which is rarely over a quarter of a mile wide. The well known greenish tremolite of Canaan is from Maltby's Quarry at the extreme south of this ridge. The rock was provisionally designated the tremolitic quartzitic limestone and its area was mapped. Sudden changes in the strike and dip of the beds were found to be particularly common in this ridge.

Now that the stratigraphy has been determined, there seems to be no reason to doubt that this ridge marks the course of a great reversed fault, which in its upthrown limb brings the Canaan Dolomite against the newer beds in its western or underthrown limb. The development of tremolite is ascribed to the profound shearing which has occurred along the fault plane, and the ragged dolomite filled with quartz veins to fracturing or crushing and recementing of the fragments by the silica of waters which have percolated along the fractures—in other words, it is a fault breccia. The ridge has survived as a topographical feature, because of the framework of quartzite and vein quartz and the imbedded crystallized silicates in the dolomite. The fault line may be followed by these characters from near Sheffield village to Maltby's Quarry, northwest of South Canaan, a distance of about ten miles. To the northward it probably connects with some of the faults of Vosburgh Hill, but its course here has not been followed. To the south of Maltby's Quarry the fault is followed in the direction of the prevailing strike to the northeast base of the Cobble,[1] which base it coincides with for some distance. This, as will be more fully shown later when that area is described, is indicated by the Cambrian Quartzite being absent, the actual contact of gneiss and apparently overlying Canaan Dolomite being exposed. On the west base of this narrow hill, the quartzite is present separating the gneiss and dolomite, and it also runs around the north end of the hill to

[1] At South Canaan. This is not the Cobble already referred to and located on the map (Cf. Plate V.)

stop abruptly at the northeast base. The well known white pyroxenes of Canaan come from the dolomite adjacent to the

FIG. 5. Map and section of the vicinity of the Housatonic Fault, southwest of Canaan village. Scale and legend the same as in Plate V.

fault line, on the road running immediately at the east base of this hill, and are much the largest that have been found in the

region. The fault probably extends a considerable distance farther to the southward but its course has not yet been traced. The northern course of the fault is indicated on the map.

Starting at the Maltby Quarry, where the surface rock on both sides of the fault line is Canaan Dolomite, and going northward, to the west of the fault line the generally northerly pitch carries the beds lower and lower so that Egremont Limestone is met before Sheffield is reached. On the east, however, no such pitch exists, and Canaan Dolomite is the surface rock for the entire distance. The Riga Schist has not been found in actual outcrop abutting against the fault plane and separating the two calcareous horizons, but this is explained by the absence of outcrops along the river valley. The map and section in Fig. 5 are introduced to indicate how the Riga Schist is believed to meet the dolomite at the fault line. This map is drawn on the same scale and has the same legend as Plate V. An examination of Plate V. will show how the hard Riga Schist of Miles Hill has caused a deflection of the Housatonic River to the eastward in that vicinity. The important easterly deflection which exists in the vicinity of the Canaan Camp Ground (cf. Fig. 5) is believed to be caused in the same way. The low area between the river and the road to the west of this bend is bare of outcrops, but Riga Schist is encountered on the road and covers a considerable area west of it. On the east of the river at this bend the tremolitic Canaan Limestone is encountered almost at the river's bank. There seems, therefore, reason for believing that in this vicinity the fault follows the river and that the two rocks abut against one another at the fault plane.

To the southward of the Maltby Quarry the fault is of a somewhat exceptional character, since the prevailing northerly pitch of the beds to the west of the fault line brings beds lower than the dolomite (First Cambrian Quartzite and then Cambrian Gneiss) to the surface in the Cobble. The upper limb of the fold is no longer the overthrown limb, but it is forced to a lower position. We have here, then, an example of a fault, which at the north is a rather steep overthrust with Canaan Dolomite over

Egremont Limestone, and at the south end a reversed fault with the same rock over Cambrian Gneiss. It follows that the throw varies most widely. At some fulcrum point, which must be near the Maltby Quarry, this is practically *nil*. To the north of that point, the western limb has been downthrown an amount which steadily increases in going north, till in the vicinity of Sheffield it can hardly be much less than a thousand feet. To the southward of the Maltby Quarry, the western limb has been upthrown and the amount of this upthrow at the Cobble must be several hundred feet.

The occurrence of two very thin quartzite lenses, which follow a line parallel with the fault line along "Silver Street" in Sheffield (Cf. Plate V.), is reason to believe that two secondary faults there run parallel to the main fault.

Additional evidence of the main overthrust is the occurrence of numerous very large boulder-like masses of the tremolitic quartzitic dolomite, resting on the Riga Schist to the east of the road on the northeast flank of Miles Hill. It might be argued that they are of glacial origin, since the direction of glacial movement in this section is favorable, but they could only have come from a point just across the river, and such masses are not distributed over the area to the southwest. Such masses are, however, found in abundance along the eastern side of the overthrust for almost its entire length, and it therefore seems most probable that they are fracture blocks produced in the faulting, which have rounded through weathering, and as degradation has gone on, have settled down upon lower beds of the mother rock, and to some extent also upon the Riga Schist west of the river.

This reversed fault presents some analogies with the overthrust faults of the southern Appalachians described by Hayes,[1] and those in New York described by Darton[2], but the fault plane

[1] The Overthrust Faults of the Southern Appalachians, by C. W. HAYES. Bull. Geol. Soc. Am., Vol. 2, pp. 141-154, pls. 2-3. Cf. also Willis and Hayes, Am. Jour. Sci. (3) XLVI, pp. 257-268. Oct., 1893.

[2] On two Overthrusts in New York, by N. H. DARTON. Bull. Geol. Soc. Am., Vol. 4, pp. 436-439.

has here a steeper hade, so that the older dolomite has been carried only a short distance over the newer beds.

Metamorphism along the fault.—Of considerable interest is the recrystallization which has taken place along the fault plane. The tremolite of the Housatonic ridge, and the large pyroxene crystals of the east base of the Cobble at South Canaan, must be explained in this way. The ragged quartzitic dolomite rock which characterizes the Housatonic ridge throughout its entire extent and is not found elsewhere in the region, is believed to owe its characters to a crushing along the fault and a recementing of the fragments by a vein quartz—it is in other words, a fault breccia.

In the vicinity of the great thrust planes of the Northwest Highlands of Scotland, which have been so carefully studied by Geikie, Peach and Horne, and their associates of the Geological Survey of Scotland[1], schistose structure and new minerals have been developed by the shearing, micas, hornblende, actinolite and garnet being produced in this way[2]. Another instance of this sort is furnished by the overthrusts of the Rocky Mountains along the line of the Northern Pacific Railway.[3] These thrusts have likewise produced metamorphism of the beds along the thrust planes, argillaceous layers being made schistose and limestones being whitened and cracked.

Thickness of the Egremont Limestone.—In the Mt. Washington paper, I have shown that the thickness of the Egremont Limestone in the southern portion of the summit plain is less than one hundred feet, and that a little farther south it probably dies out altogether. In the northern portions of that area, where it

[1] The Crystalline Rocks of the Scottish Highlands, by ARCH. GEIKIE, B. N. PEACH, and JOHN HORNE. Nature, Vol. XXXI., pp. 29-35, Nov., 1884.

Report on the Recent Work of the Geological Survey in the Northwest Highlands of Scotland, Based on the Field Notes and Maps of Messrs. B. N. Peach, J. Horne, W. Gunn, C. T. Clough, L. Huxman, and H. M. Cadell. Communicated by A. GEIKIE. Quart. Jour. Geol., Soc., London, Vol. XLIV., pp. 378-441, 1888.

[2] Nature, Vol. XXXI, p. 35.

[3] Report on the Geological Features of a Portion of the Rocky Mountains, by R. G. McCONNELL. Ann. Rep. Geol. Surv. Canada, (New Series) Vol. II., 1886, p. D34.

attains a greater thickness, no measurements could be made, though it can safely be said that it does not exceed a few hundred feet. The relations made out in the area now under consideration, allow of a thickness which agrees well with that found in Mt. Washington. A locality which illustrates this will be here briefly mentioned, because the structure is so simple as to afford reliable results. The locality is a knoll called Pine Hill, lying at

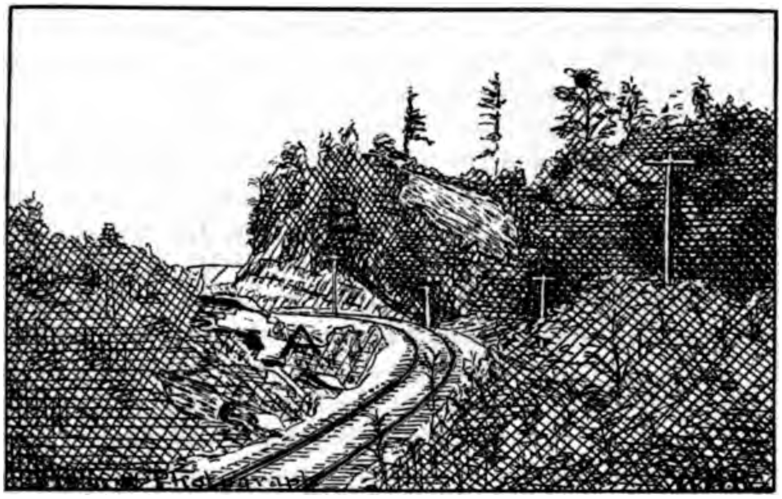


FIG. 6. View of Pine Hill on the southeast flank of Tom's Hill, seen from a point to the west. A, Riga Schist. B, Pine Hill composed of Egremont Limestone. C, Approximate position of cap of Everett Schist.

the southeast foot of Tom's Hill south of the railroad. The dips are low, due entirely to pitch, and the thickness of the limestone less than 100 feet. (This locality is marked P on the map). North of the track (A in Fig. 6) is seen the Riga Schist pitching south at an angle of about 35°. Across the track and a little farther east is Pine Hill (B), composed of a pure, white limestone dipping conformably over the schist, and capped on its south slope by a thin layer of the Everett Schist. The outcrops of this rock are hidden in the view, but their approximate position is shown by C. The thickness of the Riga Schist and the Canaan Dolomite have

not been measured. The former probably has a thickness of much less than a thousand feet. A locality where the Canaan Dolomite appears below it in the core of a fold, is shown in Plate VII., Fig. 3.

Conclusions.—Some of the results of this study may be summed up in the following statements:

I. The district is geologically closely connected with Mt. Washington, and contains the same horizons, viz: Canaan Dolomite, Riga Schist, Egremont Limestone, and Everett Schist. For the most part the same general lithological features characterize these horizons as on Mt. Washington. Pyroxene is a characteristic mineral in the lower but absent from the upper calcareous member. Garnets and staurolites are abundant in the lower but absent from the upper schist member. Locally important beds of calcareous schist occur in the Egremont Limestone. The Everett Schist differs from much of that of Mt. Washington in being essentially non-chloritic. The Egremont Limestone has a thickness of less than 100 feet in the southern part of the area.

II. The tongue-like outline of the area containing schist exposures is due to a general northerly pitch of the flexures to the west of the Housatonic River, though the local pitch of these flexures varies greatly and is as often south as north. Most of the prominent ridges are anticlinals of the Riga Schist, the few areas of Everett Schist being synclinals and largest where basins are formed by a coincidence of longitudinal and transverse synclinals. The schist areas exhibit an arrangement in four[1] east and west belts having each a width of about two miles, as the result of four marked undulations in the crest lines of the flexures. Particularly toward the north these belts are further subdivided by a secondary series of undulations a half mile or more in width, and a tertiary series of yet smaller waves can in some cases be made out at localities. These facts show that the area has been subjected to compression in a north and south direction.

[1] (1) Bear's Den, Barnard Mt., and Johnny's Mt.; (2) Horse Hill, Peck's Hill, etc.; (3) Northern Chapinville area, Tom's Hill, and Miles Hill; (4) Southern Chapinville area, and area No. 6.

as well as in an east and west direction. The compression from the north and south has produced no dislocation, as no transverse faults have been discovered.

III. The rocks of this area have been very sharply folded. The types of folds are the unsymmetrical, with short and steep western and longer eastern limbs, and the overturned and sharply compressed fold with an easterly dipping axis. Reduced and ruptured underthrown limbs are not uncommon, but the evidence is that the extent and the throw of these minor faults is very slight. On the southeast flank of Tom's Hill this has produced the structure which Suess has called *Schuppenstruktur*. I would suggest, as an English equivalent of this term, *weather-board structure*.

IV. An important reversed fault, which has been termed the Housatonic Fault, has a northerly course along the eastern border of the area of schist ridges. Its course very nearly coincides with that of the Housatonic River for a considerable distance. The fault is traced from near Sheffield village to beyond South Canaan, a distance of about twelve miles. North of the Maltby Quarry it has the characters of an overthrust which increases in throw in going north, owing to the northerly pitch of the beds to the west. This has carried the Canaan Dolomite of the eastern or normal limb over the newer Egremont Limestone and Everett Schist of the western reversed limb. South of the Maltby Quarry the western limb has been upthrown, bringing Cambrian Quartzite and Gneiss against the dolomite. The dolomite has been extensively crushed and metamorphosed along the fault plane. Tremolite and white pyroxene have been extensively developed in the vicinity of the fault plane, and vein quartz has cemented the dolomite fragments together, producing a fault breccia.

It is very probable that the rapid alternations of pitch which characterize this area are not altogether unusual. It is only rarely, however, that the areal relations shed so much light upon the form of the crest lines and trough lines of folds. What has been set forth will, I think, show that evidences of general

pitch, to be reliable, must be based on observations made over a considerable area.

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EXPLANATION OF PLATES.

PLATE V.—Geological Map of portions of Sheffield, Mass., and Salisbury, Conn., based on the Sheffield and Cornwall sheets of the Topographical Map of the United States by the U. S. Geological Survey. Scale 1 : 62,500.

PLATE VI.—Series of Geological Sections to accompany Plate V. Their location is indicated on the map (Plate V.) Horizontal Scale: one inch equals one mile. Vertical Scale: one-eighth inch equals five hundred feet.

PLATE VII.—FIG. 1. View showing the southern termination of one of the longitudinal undulations of the western schist anticlinal, as seen from the west. A, Southern limit of a ridge of Riga Schist (No. 10). B, Turnip Rock (Everett Schist). C, Barack M'Teth (Everett Schist). D, Knoll of Riga Schist. E, Tom's Hill in the distance. F, Ridge No. 6 (Riga Schist). The dotted and dashed line shows the approximate boundary between the Riga Schist and the Egremont Limestone, and the dotted line the approximate boundary between the Egremont Limestone and the Everett Schist.

FIG. 2. View of schist ridges separated by belts of limestone at the southeast base of Tom's Hill near the railroad bridge. A, B, C, Schist ridges. D, Slope of Tom's Hill where a fourth schist belt is hidden in the trees.

FIG. 3. Canaan Dolomite occupying the core of an anticlinal of Riga Schist at the south end of area No. 6. The view looks southeast. A, Outcrop of Riga Schist. B, Canaan Dolomite. C, Riga Schist.

THE NEWTONVILLE SAND-PLAIN.

1. *Introduction.*—During the past year the writer has studied the Newtonville (Massachusetts) sand-plain under Professor Davis, of Harvard University, and after studying the deposit as it now exists, made a detailed map of the plain with its feeding esker. Then a model of the region was made in clay on the scale of 1:4000. This clay model was photographed, and is here reproduced in half-tone, in Fig. 1, Newtonville Sand-plain. The conditions of formation were then studied, and a second model constructed, showing a conjectural relation of deposits to the margin of the New England ice-sheet at the time of its formation. A photographic reproduction of this is given in Fig. 2, Ice-sheet Restored.[1]

2. *Making the models.*—The clay was built up in a solid mass to the greatest required height, and the details of form were then cut with graving tools. In making such models it is essential that the foundation for the clay should be firm and not liable to warp. A slate slab, or a piece of heavy plate glass answers the purpose well. While at work on the model it is important to keep the clay moist. So a box lined with rubber cloth should be provided, large enough to cover the clay without touching it, and an inner layer of muslin put in to hold the water. When the model is ready to have a plaster mold made, the edges should be trimmed square, tapering slightly up from the slate so that the mold will slip off easily, the surface oiled, boards placed an inch and a half from the four sides, and liquid plaster poured over it. After the plaster has set, it may be wedged up from the slate or glass, and lifted from the clay. Then the plaster negative should be carefully washed with a brush to remove all oil or clay stick-

[1] Teachers or others who desire copies of models, photographs, or lantern slides can arrange for them by corresponding with the writer.

ing to it, and when hardened with a thin solution of glue and dried it is ready for the taking of a paper positive. This *papier-maché* model is a close representation of the original clay.

3. *A late glacial deposit.*—A glance at the first model will show the typical form of these delta deposits, the esker like an arm, and the sand-plain like a hand with its finger lobes. The esker rises in height as it approaches the head of the plain. The top of the sand-plain slopes very gently downward from the head to the top of the lobes, but the front slopes of the lobes are much steeper, about twenty degrees.

The sand and gravel are so little disturbed that the deposit cannot be pre-glacial. That the deposit was not made by marine or fluviatile action is shown by the three following considerations. First, an aqueous deposit of gravel, composed of fragments from the crystalline high-lands between two and three miles to the north, should have extended originally from its source outward; but the amount of denudation and transportation required to cut out these delta deposits from a continuous sheet extending across the Charles river to the crystalline highlands on the north, whence a large part of the fragments come, would be greater than the post-glacial denudation that has been measured elsewhere. Second, the delta front and the even sloping delta-plain imply standing water, and if this water level existed for so long a time as would be required to form such an extensive deposit, we should expect to find more evidence of its shore line in other localities than now exists. Third, the constructional forms, cusps, hollows, kettle-holes, at the head of the sand-plain are so marked that one cannot believe them to be the product of erosion. The kettle-holes and marshy depressions show that the plateau tops did not extend much farther than at present.

The dwindling New England ice-sheet, whose existence is proved by other facts, supplies all the conditions necessary for the construction of such discontinuous deposits. The ice-sheet could not have advanced over the plain after its deposition, for the sand and gravel would have been easily carried away. There is no gullying of the sides of the sand-plain; therefore it was

FIG. 1.

formed not so very long ago. But the gravel is evidently of glacial origin, being of angular and subangular pebbles, of great variety of material. The conclusion seems inevitable, therefore, that these deltas were formed during the retreat of the ice-sheet.

4. *Stagnant, melting ice.*—In the retreat of the ice-sheet there were parts at least which became too thin to move. As Professor Davis has said:

> During this time it must have melted irregularly, presenting a very uneven, ragged front, from which residual blocks may have been frequently isolated; and it must have endured longest in the valleys, where it was thickest, not only by reason of its greater depth, but also because its surface there, where motion had been fastest and longest maintained, must have been higher than on the hills—this being homologous with the variation in the thickness of a Swiss valley glacier from middle to sides."[1]

It seems to me that we must consider the change to have been gradual from a moving glacier to a stagnant one, and that there may have been times of renewed activity with a forward motion, even in the period of decline. Such forward motion may have had some influence in shifting the course of esker rivers and so have determined where the next sand-plain was to be built. So far as I know, this point has not been worked out in the field.

Crevasses are formed as the ice moves, and change their position according to the tensions in the mass of the glacier. When the tension from motion has ceased, and the ice has become a diminishing, drift-covered mass, the condition represented in Fig. 2, we should not expect to find any crevasses remaining. They would either have been closed by the forward motion of the ice, or would have lost their distinctive character by the excessive melting of their sides, while the water would have washed detritus into them covering the underlying ice, and preventing it from melting as fast as that on either side. Such protection of the ice by detritus must have had great influence in determining the surface forms of the stagnant ice-sheet, as is shown in Professor Russell's account of the sand cones and the deposits in glacial lakelets.

[1] Bull. Geol. Soc. of Am., Vol. I., p. 196.

5. *Comparison of models.*—Turning from Fig. 1, which shows the deposits as they exist to-day, to Fig. 2, which shows the theoretical conditions of formation, it will be seen that the northern half is covered with ice, from which is issuing an esker river. The ice in the second is represented as fitting into the intercuspate hollows shown at the head of the sand-plain in the first model, and is from one hundred to three hundred and fifty feet thick. Toward the rock hills on the east and west it falls off, as would be the case where the ground was higher. The ice has a convex curving surface in front, with contours softened by melting, while on top it is approximately level with here and there surface streams, moulins, and perhaps a little lake.

The three little knobs of older date than the sand-plain standing near its front margin, can be seen in both models. The till-covered hills of bed rock are also the same in the two, but in the second the water stands higher up on their sides. The second model being a trifle larger, a little more of them is shown on the edges. The group of hummocky kames, shown to the southwest of the sand-plain in the first model, is covered in the second by the body of standing water into which the esker river flowed.

6. *Esker river.*—Professor Chamberlin has given us the very helpful distinction between "kame" and "esker" (osar), from the use of the words in Scotland and Ireland respectively. The former is used by the Scotch for their irregular mounds and hillocks, so typically shown in that country, and which, if developed at all in lines, have their axes at right angles to the direction of ice flow; and the latter for the Irish ridges of sand and gravel, beds of former glacial rivers, which have their axes parallel to the lines of motion in the ice. This terminology is here followed.

In the first model the esker, a ridge of sand and gravel, fairly stratified, may be traced from the middle of the northern end, where it is some ten to twenty feet high, curving eastward and then southward again, gently rising to some seventy feet above the alluvial plain shown on the northwest corner of the model of the sand-plain, and one hundred and thirty feet above mean tide.

Then it falls ten feet, and, curving a little to the west, rises thir feet to where it reaches its greatest elevation, one hundred ar fifty feet above mean tide. This is also the elevation of tl front of the sand-plain. At this point it breaks up into sever more or less clearly defined branches, which distribute the sar to build up the delta in the estuary.

These branches fall off in height towards the head of the san plain, as is often seen in similar deposits elsewhere. As it has bee shown that the amount of post-glacial erosion has been sma this depression must be due to conditions existing while the i was present. The first model shows a large kettle now occupie by a pond which lies north of the sand-plain and east of th esker. This depression, being filled with ice after the course the esker river was changed, must have had an outlet, and as th main body of ice would have prevented the formation of an out let on the north, it seems reasonable to suppose that this wate quietly cut through a slight sag in the esker to the west. Thi cutting would have continued until the ice-sheet had retreate farther north, and the ice block in the kettle had melted, and it depth would be governed by the amount of the lowering of th water in the estuary, caused by rising of the land.

Two branches from near the north end of the esker run in cusps at the head of a second smaller sand-plain deposit, form when the ice-front had retreated some two thousand feet, ar while the ice remained at this second point there would ha been no outlet for the water to the north. The frontal lobes this second sand-plain are not at all typically developed.

7. *Delta streams.*—In front of the openings of the esker tu nels will be seen the depositing streams breaking up into mar branches, as Professor Russell has described them in Alask Some of them are represented as having already ceased flow to the edge of the delta, and are fast filling up; othe are pushing out their resulting lobes as far as they can reacl while a third class are supplying detritus to those in front, ar are building up their channels to give themselves greater carr

[1] See Malaspina Glacier, page 238.

FIG. 2.

ing power by increasing their slopes. The front lobes are too strongly shown in the photograph, Fig. 2, as they were left to show the limits of the delta. In the *papier-maché* copies, the water completely covers the slopes of the lobes.

On this deposit, which is 4000 feet from east to west, and 2000 to 3000 feet from north to south, there is only one small kettle-hole. This lack of kettle-holes, so abundant elsewhere, may be taken as an indication that the ice-sheet was comparatively continuous at this time. It evidently became more broken immediately after the course of the esker stream was changed, as there are several kettle-holes to the north of the sand-plain.

8. *Superglacial streams.*—These are represented on the model as smaller than the main channels below, and more inconstant in direction. Their development after the closing up of the crevasses has been made the subject of special study, and its results are shown on the model. Other conceptions of this surface will no doubt occur to many, and any criticism or suggestion will be gladly received. One of the processes that has been a prominent factor in the determination of the form of the surface is that described above, where the detritus in the bed of the stream protects the underlying ice. Little accidents of melting and washing would shift the course of these streams, so that the arrangement of them upon the surface would not be shown by any deposits to-day. As soon as one of these streams found an opening through the ice, a moulin would be formed.

9. *Moulins and kames.*—In the second model I have made moulins in the ice-sheet above the kames in the first model, though I should not like to be understood as affirming that all these kames were surely formed in this way. It is quite probable that further study would show facts pointing to several geneses. Professor Chamberlin says, in speaking of the formation of similar deposits :

"No existing agency, by any extension of its magnitude, is at all competent to account for their localization. The formative agency, or combination of agencies, must have produced, at once, local assortment and local heaping of the assorted material, or, in other words, the assorting waters must have

been confined and concentrated in their derivative action, and likewise constrained so as to heap their material into tumuli, whose location was determined by the constraining agency more than by any feature of the local topography or other present condition."[1]

That some kames are moulin-kames seems to be undoubted, and perhaps we may best picture to our minds their formation by turning an hour-glass and watch the sand heap itself up. A certain amount of stratification will take place in air, which would be increased when the air is replaced by water.

10. *Shore-line.*—With the working hypothesis that this sand-plain was formed in a body of standing water, I reached the conclusion that it was at the head of an estuary. With the existing topography to the south it is almost impossible to conceive of the water as having been enclosed. Such a pond would require too many dams not now existing. If one accepts the delta front as proof of a body of standing water, he seems forced to conclude, on looking over the ground, that the Newtonville sand-plain was built in an arm of the sea. If so, the estuary must have connected with the Atlantic along the present course of the Charles river and through Mother brook to the Neponset. It must have had a very temporary shore-line at any given level, as there is hardly a trace of it now on the till-covered slopes, except in one place on the east bank of the Charles river, about a mile southeast of Newton Upper Falls where Dr. T. W. Harris found a faint cliff, as if made by shore cutting, with a long, gently shelving slope below it. In representing this shore-line on the second model, I have tried to show no beach effect, but to indicate that the land was but recently submerged, and that the water conformed to the contour of the till-covered slopes.

11. *Relation to other sand-plains.*—The intimate connection between the Newtonville sand-plain and the one immediately to the north of it, branches of the same esker running to each, suggests a connection of this bit of the history of our New England ice-sheet with other portions. Were the Auburndale sand-plains formed before or after the Newtonville? What other esker

[1] Am. Jour. of Sci., 1884, p. 381.

rivers emptied into this estuary? When should we expect to find terraces on either side of a sand-plain, as at Pawtucket, R. I.? Why are not sand-plains of more frequent occurrence throughout the area covered by the ice-sheet? These and many other questions are suggested as we study the details of the ice's work. Their answers await the future study and research of those local observers, who will make themselves familiar with the geographic forms of their own regions.

F. P. GULLIVER.

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THE STRUCTURES, ORIGIN, AND NOMENCLATURE OF THE ACID VOLCANIC ROCKS OF SOUTH MOUNTAIN.

THE identification of acid and basic volcanic rocks in the South Mountain, Pennsylvania, has already been announced.[1] This announcement has been further substantiated by detailed petrographical study which it will be the purpose of a later communication to discuss. The present discussion of these rocks will be limited to the acid volcanics, and its object will be; a) to show that the acid volcanics were originally identical with their recent volcanic analogues; b) to further show that their present differences are due to changes subsequent to solidification, chief among which has been devitrification; and c) to propose a name for them that shall express these facts. The structures, which will be described in the course of the paper, will be considered a sufficient guarantee of the igneous origin of the rocks which possess them, without further proof on that point.

Three distinct rock types have been recognized in the South Mountain. (1) A silicious sedimentary formation, represented by a quartzose conglomerate, a sandstone, and a compact quartzite. This is rarely accompanied by an interbedded argillaceous slate. The age of these sediments has been recently determined as lower-Cambrian by Mr. Walcott[2] from the discovery of fossils in the interbedded slates. Underlying these Cambrian sediments, but exposed by erosion for many square miles (150-175), are two types of volcanic rocks, distinctly different in chemical composition but affected by like conditions of con-

[1] G. H. WILLIAMS: The Volcanic Rocks of South Mountain, in Pennsylvania and Maryland. Am. Jour. Sc., XLIV., Dec., 1892, pp. 482-496, pl. I. The Scientific American, Jan. 14, 1893.

[2] C. D. WALCOTT: Notes on the Cambrian Rocks of Pennsylvania and Maryland from the Susquehanna to the Potomac. Am. Jour. Sc., Vol. XLIV., Dec. 1892, p. 481.

solidation and subsequent alterations. (2) In the northern part of the range a brilliantly colored acid volcanic rock predominates. It is porphyritic or non-porphyritic, amygdaloidal or compact. It is accompanied by pyroclastics and breccias. It is sometimes sheared into a fissile slate or sericite schist. (3) Toward the south and extending into Maryland a dark green basic volcanic rock predominates. This is also amygdaloidal or compact, accompanied by pyroclastics or breccias, and usually rendered schistose by pressure.

The acid volcanics.—While some of the acid volcanics are typical quartz-porphyries, others possess a groundmass which, although holocrystalline, contain the evidence of a distinctly different original character. It it this important portion of the acid flow, which will be more particularly treated in what follows. Certain conspicuous structures of the groundmass contain the history of the rock and merit a detailed description.

Fluidal structure.—The fluidal structure, which is a familiar one to all students of rhyolitic lavas, is a marked feature of these pre-Cambrian volcanics. Delicate lines of flow are brought out in great detail by weathering or are painted in brilliant colors in the material washed by the mountain brooks. The microscope shows globulites of magnetite, and hematite, and indefinite opaque microlites following sinuous lines of flow, twisting around the phenocrysts and imparting to them the appearance of eyes.

Micropoikilitic structure.[1]—This name has been given to a structure which is almost universally present in the acid and more rarely in the basic volcanics of the South Mountain. It consists in the presence in the groundmass of irregular quartz areas enclosing micolites of lath-shaped feldspars or other minerals with independent optical orientation. This structure between crossed nicols gives a pronounced mottled or patchy appearance to the groundmass, an appearance which has not infrequently been noted in volcanics of all ages. It has been variously described, usually without being named, in quartz-

[1] G. H. WILLIAMS: On the Use of the Terms Poikilitic and Micropoikilitic in Petrography. Jour. of Geol., Vol. I., No. 2, February-March, 1893, pp. 176–179.

porphyries, felsites, porphrites, peridotites, and rhyolites by numerous writers.[1] This structure was also found in the pre-Cambrian felsite of Georgia,[2] and in felsites of the same age in the neighborhood of Boston,[3] and from Marblehead Neck, Mass.

While the term micropoikilitic is not restricted to a quartz-feldspar intergrowth, in most of the occurrences described these have been the component minerals. In the rocks under discussion the feldspathic material is often so abundant as not to permit of the determination of the mineral character of the host. In such cases, however, a clue to the nature of the cementing material is found in its optical continuity with the porphyritical quartz. The feldspar phenocrysts, on the other hand, do not

[1] R. D. IRVING: Monograph V., U. S. G. S., Copper-bearing Rocks of the Lake Superior Region, pp. 99–100, Pl. XIII., Fig. 13–14, 1883.

G. H. WILLIAMS: Neues Jahrbuch für Min., etc. B. B. II. 1882, S. 607, Pl. XII., Fig. 3. The Peridotites of the Courtland series. Am. Jour. Sc., Vol. XXX., p. 30, Vol. XXXIII., p. 139.

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A. C. BRÖGGER: Der Mineralien der Syenitpegmatitgänge der südnorwegischen Augit- und Nephelinsyenit. Groth's Zeitseh. für Krys., etc., Vol. XLV., p. 546.

OTTO NORDENSKJÖLD: Zür Kentniss der s. g. Hälleflinta des Nördostlichen Smalands. Bull. Geo. Ins. Upsala, No. 1, Vol. I., 1893, p. 232.

[2] A section of this felsite, loaned by Professor Pirsson, possesses an interesting and striking resemblance to the South Mountain acid volcanics, and indicates the southward persistence of this rock type.

[3] Thin sections of these felsites were kindly loaned by Mr. Diller. They have many microscopic features in common with the South Mountain rocks, and like them were first referred to a sedimentary origin. J. S. DILLER: Felsites and their associated Rocks north of Boston. Proc. Bos. Soc. Nat. His., Vol. XX., Jan. 21, 1880. Bull. Mus. Comp. Zoöl., Harvard College, whole series Vol. XII., Geol. series Vol. 1.

affect the orientation of the cement. Where the rock is coarser grained, as is the case in some of the basic volcanics, the character of the cement can be directly tested and the material proved to be quartz.

While in some cases this structure is undoubtedly of primary character, as Professor Iddings considers it to be in many porphyrites, in a large class of rocks its secondary origin seems equally plain. Dr. Irving, who very early described this structure in the acid lava flows of the Keweenawan series, thus speaks of its origin.[1] "Whether this secondary quartz may ever be rather a result of devitrification than a truly secondary or alteration-product I have no means of deciding, though it is certainly the latter often, and I should suppose always. It surely can have no connection with the original solidification of the rock." Observations made on the South Mountain rocks likewise point to a secondary origin for these quartz areas. As the origin of the structure is of importance in its bearing on the question of the primary or secondary character of the crystalline groundmass, these observations will be briefly mentioned. In a specimen of basic lava from the railroad tunnel near Monterey the outline of lath-shaped feldspars forming an ophitic structure, which is undoubtedly original, is completely preserved. None of the original constituents of the rock remain, however, unless some of the titaniferous iron oxide is original. The rock consists entirely of quartz, epidote, magnetite (or ilmenite), and leucoxene. The quartz acts as a cement for the other minerals, forming irregular interlocking areas which are quite similar to the micropoikilitic areas of the acid rocks and which produce in polarized light the familiar patchy effects. Fine cracks traversing the rock, and parting the ferro-magnesian phenocrysts (now represented by epidote) are plainly prior to the quartz areas in which they become invisible. There can be no question as to the secondary character of the micropoikilitic structure in this case.

In the acid rocks the quartz areas are frequently more or less oval and outlined by a microfluidal arrangement of globulites,

[1] Opus cit., p. 100.

longulites and trichites of iron oxide. Zirkel figures and describes a similar appearance in the rhyolites of the 40th parallel.[1] He speaks of faint granular lines "which by their fluidal running form a net with a multitude of meshes of oval shape." The meshes are filled by one of two types of crystallization, the micro-felsitic or the spherulitic. The lines suggested to Zirkel perlitic parting. In the ancient lavas of South Mountain the meshes are filled by the micropoikilitic areas or by spherulitic crystallization or by intermediate stages of alteration, that is, spherulites more or less broken up into micropoikilitic areas. In the trichitic spherulites of the modern rhyolites[2] there is an appearance similar to the micropoikilitic mottling, caused by the breaking up of the radiating spherulitic fibers into irregular areas which extinguish differently; just such an intermediate stage between the spherulitic and a completely micropoikilitic crystallization as has been noted in the ancient volcanics. These observations suggest that the micropoikilitic structure represents recrystallized spherulitic growths when it is not the direct results of infiltration and devitrification. In many cases, the crystallization has undoubtedly never been spherulitic, if however, the micropoikilitic structure has been shown to be subsequent to spherulitic crystallization, that is, to the consolidation of the rock in numerous instances in the acid volcanics, selected from widely separated localities in the South Mountain, the presumption favors the secondary origin of the micropoikilitic structure wherever present in these rocks.

Spherulitic structure.—Two sorts of spherulitic crystallization are present in these rocks. They differ in no essential respect but are unlike in appearance. The most numerous spherulites are also the simplest and smallest. They are colorless microscopic spheres, scarcely or not at all perceptible in ordinary light but showing the usual distinct dark cross between nicols. Spheru-

[1] Vol. VI., Geo. Exp. of the 40th parallel, Fig. 1, Pl. VI., Fig. 1, Pl. VIII.

[2] Sections of material from the Rosita Hills, Colorado, and of the Obsidian Cliff, Y. N. P., were kindly loaned the writer for comparative study by Dr. Cross and Professor Iddings.

lites, in every respect similar, have been described and figured by Professor Iddings from the Yellowstone Park rhyolites.[1] While it is not impossible that some of the colorless spherulites are secondary, there is pretty good evidence that many, if not all of them, are primary. These spherulites are embedded in a base which suggests in every way a former glassy condition. In ordinary light there is no appearance of crystallization except the porphyritical. Traversing the groundmass are cracks which occasionally cut directly through a spherulite. Between crossed nicols the field breaks up into a holocrystalline quartz-feldspar mosaic in which the cracks are lost. It seems fair to conclude that the spherulitic crystallization was prior to the cracking, that the granular crystallization is subsequent, and that the cracking took place in an already solidified glass. In these facts we again find obvious indications of a secondary crystallization. In this case the process seems to have been one of devitrification. The other class of spherulites corresponds to those figured by Professor Iddings in Plate XVII.[2] They are much larger than those which have just been described; the smallest being easily discernible by the unaided eye, and the largest about the size of a butternut. Hence they become a conspicuous feature of the rock as exhibited in the field. They are rarely altogether absent, and in some localities are crowded so close together as to constitute the major part of the rock mass. When without regularity of arrangement, and when brought out in relief by weathering, these spherulites give to the rock a superficial resemblance to a conglomerate composed of rounded pebbles of uniform size and shape. The rich greys, blues, purple and red of the spherulites and matrix render this a conspicuous rock.

Spherulites become an even more striking feature of these rocks when arranged in layers such as have been described in the modern rhyolites of the Yellowstone National Park.[3] On a face of the rock normal to the layers, they appear as long

[1] Opus cit., Pl. XVII., p. 276.

[2] Opus cit. p. 277.

[3] IDDINGS: opus cit. p. 276, Pl. XVIII.

parallel bands simulating lines of bedding. Sometimes these bands are 4 m. m. wide, at a nearly uniform distance apart and of an indefinite length. In other cases they are very narrow, dwindling into mere lines and dying out, to be replaced immediately by other lenticular bands. The rock cleaves readily parallel to the planes of these bands, which have become planes of weakness and solution, and the spherulites are entirely replaced by secondary silica. This fact, imparting to the bands an opaque white color, render them the more conspicuous in contrast with the blues or reds of the rock surface.

The spherulites which remain unaltered show in the thin section clear cut, circular, semicircular, and fan-shaped outlines, and are colored purple or red by finely disseminated particles arranged either radially or concentrically in threefold zones. Feldspar phenocrysts often occupy the center of the radial growth. These well preserved spherulites are associated with a groundmass which preserves the characteristics of a glass in great perfection, and which, in ordinary light, could readily be mistaken for a fresh glassy lava. It bears the closest resemblance to the base of some of the Colorado rhyolites. Delicate perlitic parting, which because of its delicacy is usually obliterated, is here preserved in wonderful detail. The presence of innumerable globulites accentuates the perlitic and rhyolitic structures. With crossed nicols the aspect of the groundmass completely alters. All glassy structures disappear, to be replaced by granular quartz and feldspar.

It is impossible by any description to carry the definiteness of conviction as to the original glassy nature of the groundmass which the character of such rock-sections justifies. To one who has studied them in both ordinary and polarized light there can be no question as to the secondary character of the holocrystalline groundmass. One cannot escape the conviction that the rock originally consolidated as a spherulitic perlite, and has become holocrystalline by a process of devitrification.

Associated with a groundmass, whose early glassy condition is not so strongly marked, are the altered spherulites. Their spherical

shape in the hand specimen and their sharply defined outline in the thin section in ordinary light alone testify to their former presence. With crossed nicols these boundaries become inconspicuous, and the field of the microscope shows only a uniform quartz-feldspar mosaic. The crystallization within the spherulitic boundary is sometimes finer grained than that of the groundmass, or the micropoikilitic structure is present in the former when absent from the latter, otherwise the spherulite is in no way distinguished from the groundmass. In the case of the chain spherulites the alteration is complete and universal. There is, in ordinary light, an impressive similarity with the fresh chain spherulites of the Yellowstone Obsidian. The same irregularly scalloped outline, the same central chain of clear spherules. With crossed nicols the close similarity vanishes, for in the ancient rocks the radial growth has utterly disappeared. The clear spherules are composed of finely granular quartz while the sinuous border is not to be distinguished from the quartz-feldspar groundmass.

Axiolitic structure.—Closely related genetically to the chain spherulites, but unlike them in being linearly radial rather than centrally, is the axiolitic formation.[1] These have been described in rhyolites and occur somewhat sparingly in their ancient prototypes of the South Mountain.

Rhyolitic structure.—The sections in which the axiolites were observed possess a holocrystalline character, but exhibit in ordinary light flow and vesicular structures, together with stringers and shreds and curved patches of a brownish red color forming what has been called a rhyolitic structure. This latter structure, which has been figured and described by Rutley,[2] Nordenskjöd,[3] and Vallée-Poussin,[4] and on a macroscopic

[1] ZIRKEL: opus cit. p. 167.

[2] RUTLEY: On the Microscopic Structure of Devitrified Rocks from Beddgelert and Snowden. Q. J. G. S., Vol. XXXVII., 1881, p. 406, Fig. 1-2.

[3] NORDENSKJÖLD: opus cit., p. 5.

[4] VALLÉE-POUSSIN: Les Anciennes Rhyolites dites Eurites de Grand-Manil. Bull. de L'Acad Roy. de Belgique, 3d series, Tome 10, 1885, p. 271.

scale by Irving,[1] is essentially nothing else than a special phase of the fluidal structure, a phase peculiar to flowage in lava consolidating with extreme rapidity, that is, in an acid glass. The granular crystallization has developed with entire disregard to these curved patches, shreds and stringers.

Lithophysal structure.—Often the macroscopic features of the South Mountain acid volcanics disclose their original character more convincingly than does the microscope. Lithophysæ are one of the structures which are best revealed in the hand-specimen, where they are brought out in delicate relief by weathering. The rose-pink petals of the lithophysæ in a paler pink base produce quite as beautiful specimens of this glassy structure as any rhyolite shows. The *micro-pegmatitic structure* shows itself in microscopic pegmatoid groups of phenocrysts such as are found in the Yellowstone rhyolites.[2]

Perlitic parting.—That this structure is occasionally present in the South Mountain rocks in great perfection has already been noted. While its presence is a most reliable test of the former character of the rock, its absence furnishes no evidence against the previous glassy condition of the rock, both because many recent rhyolites show no trace of that structure and because it is most readily effaced by devitrification.

Amygdaloidal structure.—In some localities the acid volcanics are conspicuously amygdaloidal. The bright green amygdules of epidote in a pale pink matrix render this rock strikingly handsome. In a few instances[3] the vesicles, which, as seen under the microscope, are bordered by a broad rim, like the ground-mass in crystallization, but are separated from it by a clear zone of silica and are darkened by an abundance of black iron oxide, bear on the inner edge of this border spherulitic growths. These are surrounded by a clear zone of silica while the center of the vesicle is filled either with an opaque black

[1] IRVING: opus cit., pp. 312-313, Fig. 22.

[2] IDDINGS: opus cit., p. 275, Pl. XV., Fig. 5.

[3] In specimens from Racoon Creek at the east base of Piney Mountain, south of Caledonia Furnace.

oxide or with granular quartz. Crossed nicols show that the spherulites are oriented optically with the surrounding silica, and that the preservation of the radiate structure is due to the arrangement of impurities.' The appearance of these vesicles is very like those figured by Professor Cole,[1] who explains their formation by a dual mode of growth—a growth from the groundmass outward converging toward a center, as well as from the center. Whatever may be the facts with reference to the Roche Rosse Obsidians, it is not necessary to call into play an abnormal method of crystallization to explain the phenomena observed in the South Mountain rocks. The spherulites projecting into the vesicles, with their bases sunk into its wall, were recognized by Professor Iddings, who kindly examined the sections, as tridymite spherulites, such as form on the walls of vesicular cavities in all modern lavas.

Taxitic structure.—Still another structure which the South Mountain rocks possess in common with rhyolites is what has been called the taxitic. This consists in the intimate mingling of two portions of the magma, which, from some cause (liquation), are slightly differentiated. The iron constituent, which evidently separated out in the original glass, has been still further crowded into bands and curved lines by the secondary crystallization. The result is the production in some cases of an irregular mottling: *ataxites;* and in other cases of a more or less complex network of interlacing bands following lines of flow: *eutaxites.* This mottling and banding is rendered the more striking by a marked contrast in color. The body of the rock is light gray or pink, and the lines dark blue, gray or red, according as the iron is more or less oxidized. When the iron constituent is arranged in oval or spherical outlines, denoting the former presence of spherulites, the rock may properly be termed a *spherotaxite.*[2]

[1] GRENVILLE A. J. COLE and GERARD W. BUTLER: on the Lithophysæ in the Obsidian of the Roche Rosse, Lipari. Q. J. G. S., Vol. XLVIII., p. 438.

[2] Note sur les Taxites et sur les Roches clastique Volcanique. Bul. de l' Soc. Belge. d'Geo. et Tome V., 1893.

Trichitic structure.—The universal presence of globulites, trichites and microlites of black and red iron oxide, in flow bands, or indifferently distributed, or in concentric zones around spherulites and vesicles is worthy of mention as a further point of resemblance to the modern rhyolite. Such trichites in similar rocks have been described by various petrographers.[1] Such, in brief, is the character of the evidence for the secondary nature of some of the holocrystalline groundmass of the acid volcanics of the South Mountain. It is not easy to present the proof so that it shall carry the weight which justly belongs to it. Very much depends upon effects which it is impossible to reproduce by description, but which carry conviction to the student of these rocks. The contrasting appearance of the sections in ordinary and polarized light cannot be adequately reproduced. The disappearance under crossed nicols of rhyolitic, perlitic, spherulitic, and fluxion structures, so clearly indicated in ordinary light, and their replacement by a homogeneous holocrystalline mosaic is one of the strongest evidences of the secondary character of the crystallization. Nor are there lacking instances where the subsequent nature of the crystallization is in other ways distinctly proven, as in the replacement of radial crystallization by the granular aggregate of quartz and feldspar, which is homogeneous with a granular groundmass, as well as in the character of the micropoikilitic structure. One or more of the structures which have been described are invariably present in the acid volcanics of certain localities. The occurrences, where their structures are absent, show a genetic relationship in the field to typical representatives of the modern rhyolite.

The writer considers that the acid lava flows in South Mountain were, at the time of their consolidation, quite comparable to similar flows as they now appear in the Yellowstone National Park. Certain portions of the flow, as in the case of

[1] S. ALLPORT: On certain ancient divitrified Pitchstones and Perlites from the lower Silurian District of Shropshire. Q. J. G. S., Vol. XXXIII., p. 449.

O. NORDENSKJÖLD: opus cit.

R. D. IRVING: opus cit. p. 312.

the Obsidian Cliff, were completely vitreous save for spherulitic and lithophysal crystallization. In other localities the lava was lithoidal, and in the central portion of thick flows holocrystalline. In this way three types of acid volcanics would be developed—rhyolites, lithoidal rhyolites, and quartz porphyries. Every gradation between these types would accompany them. Thus, while there are certain areas in the South Mountain, notably the Bigham Copper Mine and Racoon Creek localities, which exhibit typical ancient rhyolites, other regions display genuine quartz-porphyries. While in the latter rocks, which constitute a large part of the acid volcanics, the groundmass may have been, and probably was, originally holocrystalline, as in some modern lavas; in the case of the former rocks, it is supposed that the groundmass was, at the time of consolidation, wholly or partly glassy. The secondary character of some of the holocrystalline groundmass once conceded, and the indications of an original glassy base recognized, it is easy to suppose that the former was developed from the latter by a process of *devitrification.*

That the process of crystallization does not necessarily cease with the solidification of a rock is well known. That the crystallizing forces are active in a glass as well as in a molten magma has been proven by experiment.[1] This action is exceedingly sluggish, and requires, unless accelerated by heat and moisture, an immense amount of time. Devitrification has been considered the result only of dynamic action.[2] While dynamic action undoubtedly accelerates the process of devitrification, if it does not initiate it, devitrification may also take place independently of dynamic action, as was the case in the famous example of the old cathedral window-glass[3] and the ancient devitrified glass from Nineveh investigated by Sir David Brewster.[4] The nature

[1] DAUBRÉE: Géologie Expérimentale, 1879, p. 158.

[2] VALLÉE-POUSSIN: Les Eurites quartzeuses (rhyolites anciennes) de Nivelles et des Environs. Bull. Acad. Roy. Sc. Lett. et des Beaux Artes de Belg. 56 annue, 3d series, Tome 13, No. 5, 1887, pp. 521–522.

[3] Brit. Assoc. Rep., 1840.

[4] Trans. Roy. Soc. Edin., Vols. XXXII., XXXIII.

of the process is in no way different from the process of crystallization in a fluid magma, save in the rapidity of the action, and is of both a physical and chemical character. It is not the purpose of this paper to discuss the other evidences of metamorphism in the South Mountain rocks. There is ample proof that both dynamic and statical metamorphism were wide spread. While the former would, by shearing, obliterate the original structures of a glassy rock and produce a slate, the latter might be an important initiatory and accelerating factor in the process of devitrification of the glassy rocks.

Nomenclature.—The character of the acid rocks has been briefly presented, and there remains to be considered a name or names which shall be descriptive of them. While the possibility of devitrification can hardly be doubted, the fact that a finely crystalline aggregate of quartz and feldspar may also be the direct product of consolidation from a molten magma is equally recognized by the writer, and to the acid rocks possessing such a groundmass the name quartz-porphryry is given. It is by no means always possible to distinguish between a primary and secondary crystalline groundmass, hence no attempt is made to draw a sharp line between the quartz-porphyries and the devitrified rhyolites.

The typical ancient originally glassy acid volcanic should be distinguished in some way by the name from the typical ancient originally holocrystalline acid volcanic. Is there any name now in use which does this? A great variety of terms has been applied to the acid type of the older volcanic rocks. Under the general group of quartz-porphyries, Rosenbusch classifies them as *microgranites*, with a microgranitic groundmass, *granophyres* with a micropegmatic groundmass, *felsophyres*, with a microfelsitic base, and *vitrophyres* (including pitchstones and pitchstone porphyries), with a vitreous base. Foqué and Lévy use microgranitite, micropegmatite and porphyr petrosiliceux as corresponding terms. By British petrographers these acid rocks have been termed hornstones, claystones, and claystone porphyries, felsites, quartz-felsites, and felsites porphyries, agreeing in this respect

with the older German usage, when they have not followed Rosenbusch. In America both German and English usage has been followed with more or less confusing results. In the nomenclature of the South Mountain rocks an effort has been made to avoid such confusion and to use such a term or terms as shall accurately describe them and all similar rocks. No one of the terms mentioned succeed in doing this. Although, perhaps, most nearly like the felsophyres, these South Mountain rocks cannot be included under that term since they now possess a holocrystalline groundmass.

In so much as many of the English felsites have been shown by Rutley, Allport, Cole, and Bonney to be devitrified obsidians and pitchstones, and thus, like these American rocks, the representatives of the glassy lavas of pre-Tertiary times, these pre-Cambrian lavas of the South Mountain might with some propriety be termed *felsites*. Felsites, however, though useful as a field name may well be objected to as an inaccurate petrographical term. It was originally used to describe an acid base, unresolvable to the naked eye, and at first supposed to be a single mineral.[1] With the introduction of the microscope this macro "felsitic" base was resolved into the microgranitic, micropegmatitic, and microfelsitic groundmass, the point of ignorance being shifted from the felsitic base, macroscopically unresolvable to the microfelsitic base, which is microscopically unresolvable. On the continent felsite has been practically replaced by these terms. British and American petographers have retained it as a field name for rocks formed of this macroscopically unresolvable base without phenocrysts or with inconspicuous phenocrysts. The South Mountain rocks are both without phenocrysts, with inconspicuous phenocrysts, and with abundant and conspicuous phenocrysts. As this irregular distribution of the porphyritical crystals may characterize a single lava flow, it does not seem a sufficient ground for a separation of rock types.

[1] GERHARD: Beiträge zur Geschichte des Weissteins des Felsit und anderer verwandten Arten" Abhandl. der k. Akad. der Wissensch. zu Berlin, 1814–1815. s. 18–26. Naumann Lehrbuch der Geognosie Band 1, 2d ed. 1858, s. 597.

It is very generally recognized that structural features are not conditioned by the geological age of rocks, but are, on the other hand, a function of the conditions of consolidation. That the conditions attending the consolidation of surface flows in pre-Tertiary times do not differ from those attending the consolidation of similar flows in post-Tertiary times has been illustrated by a wide survey of pre-Tertiary and Tertiary rocks on the part of Allport, Judd, Teall and others[1] With this recognition has come the growing conviction among petrographers that mere age should be eliminated as a factor in rock nomenclature.[2] While this is true, it is felt, on the other hand, that there should be some recognition in the rock name of the alteration which the rock has undergone subsequent to its solidification. If, at the time of its solidification, the rock presented the features of a rhyolite, as it is believed much of the South Mountain acid lava did, but since that time has become holocrystalline, both these facts, its original character and its present alteration, should be recognized in the name.

Such a result might be secured by the retention of such well established names as rhyolite, obsidian, trachyte, etc., preceded by a prefix which shall have such a designation as to indicate the altered character of the rock. The prepositions *meta*, *epi* and *apo*, as prefixes, all indicate some sort of an alteration. Their exact force has been thus defined by Professor Gildersleeve: *meta* indicates change of any sort, the nature of the change not specified. This accords with the use of the prefix by Dana in such terms as "metadiorite" and "metadiabase." These terms have been recently revived to designate rocks "now similar in mineralogical

[1]ALLPORT: Address of the Pres. of the Geo. Sec. of the British A. A. A. S., 1873, and many other writings by the same author.

JUDD: On the Gabbros, Dolerites and Basalts of Tertiary Age in Scotland and Ireland. Q. J. G. S., Vol. XLII., 1886, pp.49-97.

TEALL: British Petrography, pp. 64–69.

[2]Reyer, Tietze, Reiser, Reusch (H. H.), and Suess support the statement that age is not a just ground of distinction between eruptive rocks, and Rosenbusch considers that in no very distant future the separation of effusine rocks into an older and a younger series will prove untenable.

composition and structure to certain igneous rocks, but derived by metamorphism from something else."[1] *Epi* signifies the production of one mineral *out of* and *upon* another. This prefix has not been much used. We find it in such terms as epidiorite, epigenetic hornblende and epistilbite. *Apo* may properly be used to indicate the derivation of one rock from another by some specific alteration.

If, therefore, we decide to employ this prefix to indicate the specific alteration known as devitrifiction (*Entglasung*) we may obtain, by compounding it with the name of the corresponding glassy rocks, a set of useful and thoroughly descriptive terms, like *aporhyolite*, *apoperlite*, *apobsidian*, etc., as to whose exact meaning there can be no doubt. In accordance with this usage it is proposed to call all the acid volcanic rocks, whose structures prove them to have once been glassy, *aporhyolites*. While those which have consolidated at a sufficient depth to secure a holocrystalline groundmass should be termed *quartz-porphyries*, whether ancient or modern lavas. The writer realizes that the introduction of a new name into petrographical nomenclature is to be deplored unless it can be shown that the name is formulated in accordance with certain well defined principles. A good rock name should express composition, original structure, and, as far as possible, the process of alteration, if any, that the rock has undergone. It is thought that aporhyolite and the suggested series of similarly formed terms meet these requirements. They are, therefore, adopted as preferable to any in present use.

Paleozoic and pre-Paleozoic acid volcanics have long been studied on the Continent, Although their variation from the modern type of acid volcanic, rather than their resemblance to that type, has for the most part been emphasized by German and French petrographers, there have not been wanting able advocates of devitrification and of an original glassy base for the ancient lavas. R. Ludwig (1861), and Vogalsang[2] (1867)

[1] WHITMAN CROSS: On a Series of Peculiar Schists near Salida, Colorado. Proc. Col. Sc. Soc., 1893, p. 6.

[2] Philos. d. Geologie, 144, 153, 194.

incline to the opinion that the groundmass of certain quartz-prophyries is the result of the devitrification of a glassy lava. The late Dr. K. A. Lossen[1] (1869), on comparing the spherulitic porphyries of the Harz Mountains with the obsidians of Lipari, Mexico and Java, found the resemblance sufficiently striking to lead him to declare that "the porphyry groundmass was originally crystallized as glass, and became cryptocrystalline through molecular rearrangement." Later, Kalkowsky[2] (1874) suggests devitrification through the chemical activity of water, as the process by which the microfelsitic base of certain pitchstones and felsites was developed, and still later H. Otto Lang[3] (1877) described a macroscopically unindividualized base which is similar microscopically to the devitrified base described by Kalkowsky. Sauer (1889) considers the Dobritz porphyries as the final alteration product of a pitchstone. C. Vogel comes to the same conclusion as to the Umstädt porphyries in Hessen.

More recently Klockmann[4] (1890) describes the replacement of the spherulitic crystallization in quartz-porphyries, through secondary processes, by a fine grained aggregate of quartz and feldspar. Osann[5] (1891) describes incipient devitrification in perlite and other glassy rocks from Cabo de Gata. Finally, Link (1892) considers that it is not impossible that the fine grained groundmass of some rocks from America that are closely related to mica-syenite-porphyries, was once glassy or at least partially glassy. Many no less capable observers still hold to an original difference between ancient and recent acid volcanics, and the possibility of devitrification and original similarity is yet an open question in Germany.

[1] Beiträge zur Petrographie der Plutonischen Gestein Abh. der Berliner Akad. 1869, p. 85.

[2] Mikroskopische Untersuchungen von Felsiten und Pechsteinen Sachsens T. M. P. M., 1874, pp. 31–58.

[3] Heinr. OTTO LANG: Grundriss der Gesteinskunde, 1877, p. 43.

[4] F. KLOCKMANN: Die Porphyre der Geol. d. s.g. Magdeburger unferandes m. besonderes Berüsksichtigung d. auftretenden Eruptivgesteine Jahrbuch k. p. Geo. Land. u. Bergakad. zu Berlin, 1890, vol. XI.

[5] Z. Geol. Ges. 691, 716.

In France, La Croix[1] describes andesites from Martinique in which the glass has altered into quartz spherulites and a granular quartz aggregate. It is interesting to note that many of the hälleflinta of Sweden, which, like the South Mountain volcanics, were once described as sedimentary, are proving to be acid volcanics preserving the features of their modern equivalents. Quite recently, glassy and rhyolitic structures in these rocks have been observed and described by Otto Nordenskjöld.[2] In Belgium Vallée-Poussin seems to be the only writer who has brought out the resemblance between the eurites of that country and modern rhyolites. He describes at some length structures similar to those possessed by the aporhyolites of South Mountain. A vacillating state of mind as to the matter of nomenclature is indicated in the titles of his successive papers.[3]

In England the rhyolitic character of the ancient acid volcanics has been recognized and emphasized, and the idea of devitrification is widely accepted. Allport, Cole, Bonney, Rutley and Harker have accomplished most valuable work along this line. Dr. Wadsworth[4] was the first American petrographer to advocate the abandonment of age as a factor in rock classification; while at the same time he recognized devitrification as the process which has been forming felsites out of rhyolites. What he says is of interest in its anticipation of ideas now more generally accepted. "This devitrification gives rise in the older and more altered rhyolites to the feldspar, quartz and microfelsitic

[1] Comptes rendus, CXI., p. 71.

[2] Opus cit.

[3] Les Anciennes Rhyolities dites Eurites de Grand-Manil. Bull. Acad. R. de Belg., 3d series, Tome 10, 1885, pp. 253-315.

Les Eurites quartzeuses (rhyolite anciennes) de Nivelles et des Environs. Bull. Acad. R. des Sc. et des Beaux-Artes de Belg. 56 annue, 3d series, Tome 13, No. 5, 1887.

[4] M. E. Wadsworth: Notes on the Minerology and Petrography of Boston and vicinity. Proc. Boston Soc. Nat. His., vol. XIX., May, 1877, p. 236.

On the Classification of Rocks. Bull. Mus. Comp. Zoöl., Harvard College, vol. V., No. 13, June, 1879, p. 277.

(so-called) base that has so puzzled lithologists in the study of the felsites. The rhyolites of all volcanic rocks preëminently show lamination produced by flowing, a fact which is doubtless due to their being so siliceous. This structure and their devitrification enables us to trace a direct connection between the rhyolites and felsites, which are simply the older and more altered rhyolites. . . . . . One of the best illustrations of this is to be found on Marblehead Neck, Mass., where at least two distinct flows of felsite occur, one cutting the other. They show the fluidal structure so characteristic of rhyolites,—a character that has been mistaken for lines of sedimentation by geologists. While the enclosed crystals of orthoclase have been taken for pebbles. . . . . . While to the naked eye and under the microscope this rock shows the fluidal structure of a rhyolite, in p. l. it is seen that the base has been completely devitrified, a process that is carried to a great extent in many known modern rhyolites." No other American petrographer has so distinctly advocated the identity of felsites and ancient rhyolites in spite of the fact that many of our felsites illustrate it as unmistakably as do the English felsites. Dr. Irving[1] in his description of the Beaver Bay group of the Keweenaw series repeatedly calls attenattention to the resemblance between the ancient felsites and quartz-porphyries and the modern rhyolites, although he does not express an opinion as to their equivalence. The statement "that the degree of crystallization developed in igneous rocks is mainly dependent upon the conditions of heat and pressure under which the mass has cooled and is independent of geological time" made by Messrs. Hague and Iddings[2] expresses essentially the position of American petrographers on this question.

Apparently in none of the felsites elsewhere described have the varied structures of the modern rhyolite been more perfectly and conspicuously preserved than in the aporhyolites of the South Mountain.

[1] Opus cit., pp. 312, 313, note 5, p. 436.

[2] On the Development of Crystallization in the Igneous Rocks of Washoe, Nevada, with Notes on the Geology of the District, Bul. 17 U. S. G. S. 1885, p. 40.

The subject discussed in this paper forms a part of a thesis, on South Mountain, presented at the Johns Hopkins University. The petrographical study was conducted in the petrographical laboratory of that institution, under the immediate supervision of Professor G. H. Williams, to whose valuable suggestions and stimulating interest the writer is in every way indebted.

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Studies for Students.

GENETIC RELATIONSHIPS AMONG IGNEOUS ROCKS.

It is desirable that the student of igneous rocks should appreciate the fundamental relationships existing between various kinds of igneous or eruptive rocks so far as they are understood at the present time, in order that he may form a proper idea not only of what an igneous rock actually is, but also of the uses and limitations of the terms by which they are designated. So it has been thought desirable to present, in an elementary form, some of the data and opinions bearing upon the genesis of different kinds of rock magmas.

It can be shown that all eruptive rock masses, whether emanating from volcanic vents at the surface of the earth or found enclosed within such vents, or confined to fissures not immediately connected with actual volcanoes, with the exception of certain infrequent occurrences of sandstones, which have been forced, while in a loose and incoherent state, into cracks—it can be shown that all ordinary eruptive masses were in a completely molten or fused condition before solidifying into the rocks they now are, and hence the terms eruptive and igneous are practically synonymous.

The igneous mass or molten magma, as we know by observations at active volcanoes, may obtain a liquidity comparable to that of water,[1] which, of course, would obtain for different temperatures in the case of magmas having different chemical compositions; the less silicious magmas reaching this liquidity at a somewhat lower temperature than the more silicious ones. During the process of cooling, magmas become gradually more

[1] James D. Dana: Characteristics of Volcanoes, etc. New York, 1891, p. 143.

viscous, and crystallization generally takes place, but the two are in a measure independent operations, and the viscosity may be advanced so rapidly that crystallization is more or less completely prevented and glassy rocks result. According to the conditions under which rock magmas cool solidification will be accompanied by more or less complete crystallization. The size also of the crystals will vary with the rate of cooling, and the general texture of the rock will be affected. Different parts of one rock magma may experience different conditions of cooling, and there will result a variety of textures or structures within the mass. It may be that the textural differences are sufficiently pronounced to be given distinctive names, which become the terms by which certain kinds of rocks are designated; for example, granite, porphyry, pearlite, pumice, etc. There is then a relationship between certain kinds of igneous rocks which exists because of different conditions which have attended the solidification of various portions of one body of magma, or of several magmas alike in other respects. The significance of this relationship was long ago appreciated by James D. Dana,[1] who maintained that the textural differences among rocks were mainly due to the physical conditions under which they consolidated; an idea ably advocated and corroborated by Judd,[2] and more recently substantiated by numerous observations in many localities.

Igneous rocks often differ from one another in mineral and chemical composition; in fact, some kinds differ so widely from one another in a mineralogical sense that they possess no mineral in common. And most kinds contain the minerals which may be common to them in quite diverse proportions, and associated with various other species. Chemically they consist of the same essential constituents in variable proportions, the variations being within certain limits. But the proportions are so far from being

[1] United States Exploring Expedition during the years 1838–1842, under the command of Charles Wilkes, U. S. N., 4to. Philadelphia, 1849. Vol. 10, Geology, p. 372 *et seq.*

[2] J. W. JUDD: On the Ancient Volcano of the District of Schemnitz, Hungary. Quart. Jour. Geol. Soc., 8vo, Vol. 32, 1876, p. 292 *et seq.*

fixed for similar kinds of rocks that it would be almost impossible to find two instances in which the proportions between the essential ingredients were exactly the same. The independence of many kinds of igneous rocks might seem at first thought to be clearly established by these mineralogical and chemical divergences. This apparent independence disappears when a great number of rocks are investigated. It is found that few rocks contain the same minerals in any given proportion, and that the variable proportions of minerals produce varieties of rocks which grade insensibly from one extreme of mineral composition into another. Intermediate varieties of rocks which form transitions from one type, or distinct kind, to another have been recognized for many years. But it is becoming more and more evident that the so-called type-rocks are not more abundant in nature than the intermediate forms. It is found that particular kinds of rocks may preponderate in one region and the intermediate varieties be subordinate, but that in other localities the relations may be reversed, and the so-called transitional forms may prevail.

The mineralogical gradation of one kind of rock into another is indicated not only by the comparison of all known varieties of igneous rocks, but more especially by the study of all the occurrences of such rocks in any region where they are abundant. The absence of distinctive types, and the presence of all possible varieties intermediate between the extremes is the most noticeable characteristic. Moreover, the transitional variations are not simply represented by slightly different bodies of rock, but they may often be found to exist within one continuous rock mass. Thus, a large body of rock may change in mineral composition from one spot to another by the most gradual transitions, giving rise to constitutional facies of the main mass. Again, it is found that a large body of rock, which may be nearly homogeneous throughout, exhibits certain mineralogical facies which are like the main portion of some other rock-body in the same region; so that the subordinate variety in one mass is the predominant form in another.

Thė ability of a rock magma to change in chemical composition in different parts, so as to crystallize into different mineral combinations which correspond to mineralogically diverse rocks, does not appear to be limited to small volumes of magma, but shows itself on quite different scales; sometimes confined to a narrow dike, at others acting throughout a large mass thousands of feet in diameter. That which is seen to have taken place within a comparatively limited volume of molten magma might be reasonably assumed to be possible within much greater volumes. Nevertheless it does not necessarily follow that it has done so; conditions which may have brought about the change in one case may not exist in another.

The probability that such changes have taken place in great reservoirs of molten magma, and have brought about the chemical and mineralogical differences among igneous rocks, finds its support in other evident relationships than those of facies and the gradual transitions in mineral composition between the kinds of rocks. The nature of this evidence is twofold and consists, first, in the existence of associations of various kinds of igneous rocks in volcanic regions; and second, in chemical and mineralogical diversity between different associations of rocks, that is, between groups of rocks belonging to different regions. The association of various kinds of rocks in particular volcanic districts, and their constant recurrence in company with one another in widely distant parts of the world impressed itself upon the minds of Scrope,[1] Darwin[2] and Dana[3] in the first half of the present century, and led them to the opinion that the various kinds of lavas thus associated must have originated from some common source, that is, from a common molten magma, by some process of separation or differentiation.

Subsequently, as the chemical and mineralogical constitution of rocks became more readily determinable, it was discovered that there were chemical and mineralogical characteristics of

[1] G. P. SCROPE: Volcanos, 8vo, London, 1825.

[2] CHARLES DARWIN: Volcanic Islands, 8vo, London, 1844.

[3] Loc. cit.

whole groups or associations of rocks which distinguished them from groups in other regions. This was noticed by Judd in studying the volcanic rocks of Hungary and Bohemia, and was afterwards clearly expressed by him in defining ***petrographical provinces*** as districts "within which the rocks erupted during any particular geological period present certain well-marked peculiarities in mineralogical composition and microscopical structure, serving at once to distinguish them from the rocks belonging to the same general group, which were simultaneously erupted in other petrographical provinces."[1] A striking illustration of the individuality of a petrographical province is found in the unusual group of rocks described by Brögger,[2] from the region of Christiania. They are characterized by a high percentage of sodium and a consequent abundance of alkali minerals. Brögger calls attention to the remarkable fact that the greater part of the rocks in this district are absolutely peculiar to the locality, or nearly so, and have not yet been found in any other part of the world. The association of special kinds of rocks in different localities has also been pointed out by Rosenbusch,[3] and urged as evidence of a genetic relation between the rocks so grouped.

Certain chemical characteristics of special geographical groups of rocks become apparent when all of the chemical analyses are systematically compared and their variations plotted graphically, as has been done by the writer for the rocks of particular localities in the Yellowstone National Park, and for those of Vesuvius and vicinity, and of Pantellaria.[4] It is observed in these cases that the relations of the alkalies to one

[1] J. W. JUDD: On the Gabbros, Dolerites and Basalts of Tertiary Age in Scotland and Ireland. Quart. Jour. Geol. Soc., Vol. 42, p. 54, 1886.

[2] W. C. BRÖGGER: Die Mineralien der Syenitpegmatitgänge der Südnorwegischen augit- und nephelinsyenite. Zeitschr. für Kryst. u. Min., 8vo, Leipzig, 1890, Vol. XVI., p. 83.

[3] H. ROSENBUSCH: Microskopische Physiographie der massigen Gesteine, 8vo, Stuttgart, 1886, pp. ix., 600, 628, 767, 795, 809, 810, 821. Also in Mineral. und petrogr. Mitth. XI., 1890, p. 445.

[4] J. P. IDDINGS: The Origin of Igneous Rocks. Phil. Soc. Washington, Bull. Vol. XII., 8vo, pp. 89–214, Pl. 2. Washington, 1892.

another and to the other constituents is characteristic of the rocks of each group. A genetic relationship is clearly indicated, and it appears that the various rocks in each locality have been derived from a general magma peculiar to the locality.

The distinguishing characteristics of the rocks of different petrographical provinces which may be observed in their chemical composition also find expression in certain mineralogical peculiarities. Thus the presence of a relatively high proportion of potash will insure an abundance of potash-bearing minerals, as at Vesuvius. The relatively high percentage of soda in the rocks of Pantellaria, together with low alumina and relatively high ferric oxide, determines the prevalence of alkali-feldspars rich in soda, and of soda-bearing ferro-aluminous silicates, ænigmatite or cossyrite. The less prominent position of the alkalies in the rocks of Electric Peak and Sepulchre Mountain, and the relatively higher percentages of magnesia and iron oxide leads to the very general presence of orthorhombic pyroxene in these rocks, which is in contrast to the less magnesian and more alkaline rocks of Central France and Germany. The abundance of alkalies and general preponderance of soda in the rocks of the Christiania district expresses itself in the abundance of the alkali-feldspars and feldspathic minerals, and in the prevalence of acmite- and riebecite-molecules in the pyroxenes and amphiboles.

From this it follows that certain rocks belong in particular natural series or groups, and are absent from others, and that two natural series of rocks, when arranged according to the percentages of silica, may grade through similar ranges of silica, but may each embrace different kinds of rocks. Thus:

Silica Percentages.	*Yellowstone Park.*	Silica Percentages.	*Vesuvius and Ischia.*
48–53	Basalt.	46–55	Leucitophyre.
55–62	Pyroxene-andesite. Hornblende-andesite.	55–62	Trachyte.
64–68	Hornblende-mica-andesite. Dacite.		
70–75	Rhyolite.	69–71	Rhyolite.

In such series it happens that rocks bearing the same name differ in certain mineralogical respects, and are really more

closely allied to the chemically nearest variety in their own group than they are to the rock of the same name in another group.

It must not be inferred from the facts just given that every natural group of rocks has some peculiarity which distinguishes it from every other group. There are many natural groups or petrographical provinces, the rocks of which are identical in the minutest detail with those of neighboring or distant regions. And the limits or boundaries of such provinces are not sharply drawn in nature. In some regions the transition from one province to another appears abrupt, in others very gradual. Thus, while certain provinces exhibit distinct mineral and chemical characteristics, others appear to possess characters of several provinces.

Recognizable chemical differences may exist between groups of rocks within less than a hundred miles of one another, and again broad general features may be persistent, or at least may be prevalent, over vast areas of the globe. Within these areas, of course, subordinate variations may exist. The most impressive illustration of this law is furnished by the igneous rocks of the two continents of North and South America. The great belt of Cordilleras and parallel ranges stretching along the western side of North America abound in igneous and volcanic rocks which belong to a quite uniform petrographical province, extending from British Columbia to Mexico and Central America. They are not specially rich in alkalies, and are characterized by a very general presence of the ferro-magnesia mineral, hypersthene; local variations occur. As the eastern portion of this mountain system is approached from the west a gradual increase in alkalies is noticeable, and rocks bearing nepheline, leucite and more frequent alkali-feldspars make their appearance, containing alkali-bearing ferro-magnesian minerals. These have already been described, from Montana, Wyoming, Dakota, Colorado and Texas, and are especially well developed in Arkansas. Similar eruptive rocks have been found in the eastern portion of the continent, in New Jersey, New England and Canada.

In South America the great Cordilleran system of the Andes presents a petrographical province identical, chemically and mineralogically, with those of the North American Cordilleras, and which appears to extend throughout its entire length. In the eastern part of the continent and on the islands off its coast the petrographical province is in turn identical in many respects with the eastern province of North America; the correspondence being most pronounced between the rocks from Brazil, described by Derby[1], and those from Arkansas described by J. Francis Williams.[2]

The chemical and mineralogical qualities or peculiarities which characterize the rocks of particular groups, and at the same time serve to distinguish them from those of some other groups, are like family traits of character, and suggest the intimate relationship and common origin of all of the igneous rocks of the group. They prove conclusively that the varieties of rocks occurring at a particular center of eruption, or in a volcanic district, have been derived from some magma common to the district by a process of differentiation similar to that which has caused smaller bodies of molten magma to become chemically heterogeneous and has produced mineralogical facies.

That the process which has produced the many kinds of igneous rocks in any region, with all their transitions into one another, was a process of differentiation of an originally homogeneous magma, and not the compounding of two or more different ones, is shown by the geological relationships between the various bodies of rock belonging to a volcanic center; more especially the order in which they have been erupted. A process dependent upon any set of physical conditions, which continues active for long periods of time must yield results that are to a very considerable extent functions of time, that is, they must be

[1] O. A. DERBY: On Nepheline Rocks in Brazil, with special reference to the Association of Phonolite and Foyaite. Quart. Jour. Geol. Soc. 8vo, London, Aug., 1887. Also The Tingua Mass. *Ibid.*, May, 1891.

[2] J. FRANCIS WILLIAMS: The Igneous Rocks of Arkansas. Annual Report of the Geological Survey of Arkansas for 1890. Little Rock, 1891.

accumulative. Hence, if the process is one of synthesis or commingling, the mixture should be the more complete the longer the process has been in operation. On the other hand, if the process is one of differentiation the separation should be the more perfect as time goes on. The various bodies of rock occurring in a large volcanic region have been erupted at widely different times, and while belonging to a connected period of volcanic activity may often represent the lapse of ages. Their genetic relationship has been the result of some active principle coëxtensive with this vast time, and persistent or intermittent; the effect in either case must be accumulative.

It is found in all regions carefully investigated that there is a sequence in the eruption of different varieties of rocks which is most characteristic. From the nature of the causes leading to the extrusion of volcanic lavas, the irregularities of the conduits through which they reach the surface and the probable diversity in the physical conditions obtaining in different regions, it is to be expected that the course of events will not be the same in all cases, or constant in any one instance. Hence the sequence of rocks will not be uniform for all regions, nor will it necessarily be simple in any case. The sequence discovered by von Richthofen,[1] when expressed in general terms, is of very wide application, and is to the effect that the earliest eruptions are of rocks having an average or intermediate composition, and that subsequent eruptions bring to the surface magmas of more and more diverse composition; the last eruptions producing the most diverse forms. The transition from a magma of intermediate composition to those of extremely divergent composition, is clearly the result of a process of differentiation. "This correspondence between the petrographical and the geological succession," as Brögger[2] remarks, "appears to prove conclusively a genetic connection between successive eruptions." The same conviction has been expressed by Geikie, Teall and others. Evidences of the mixing

[1] F. von RICHTHOFEN: The Natural System of Volcanic Rocks, 4to. San Francisco, 1868.

[2] Loc. cit. p. 83.

of different rock magmas to form an intermediate modification are exceedingly local, and appear to be confined to narrow limits along the junction of one body of rock with another.

The genetic relationship between the various kinds of igneous rocks belonging to a center of volcanic activity, which is plainly indicated by their chemical, mineralogical and geological relationships, is in the nature of a generic connection. They have originated from some common magma or parent stock, and to a very large extent are characterized by whatever distinguishing peculiarity was characteristic of the parent magma. They are in this sense consanguineous. The presumably homogeneous parent magma has become heterogeneous by some chemico-physical process or processes, so that different portions of it have different chemical constitutions. The differentiation undoubtedly takes place according to fixed laws and within limitations affected by the original constitution of the magma, and by the external controlling conditions or agencies. Further than this we shall not venture in the present article. It will be sufficient to consider some of the consequences of the general principles of magmatic differentiation.

First. If differentiation is controlled by external agencies or conditions, such as changes of temperature and pressure, which depend largely on the environment of the magma, then the results of differentiation should vary when the external conditions vary. It is not to be expected, therefore, that similar magmas will always yield the same results when differentiated, within certain limits. They may have experienced quite different physical conditions. The more uniform the conditions the more concordant the results.

Second. Since the process of differentiation requires time, is progressive, and, from geological evidence already alluded to, often continues for ages, it follows that eruptions from a reservoir, where the process of differentiation is taking place, will draw off magma whose constitution will depend on the phase of differentiation attained by the parent magma. The phase will naturally depend on the time at which the eruption takes place.

Moreover, since the process of differentiation necessitates the coëxistence of differently constituted derived magmas in various parts of the parent body or reservoir, the kind of magma drawn off ,at an eruption will also depend upon the portion of the reservoir drawn from.

Third. If, in a given region of eruptive rocks, each body of rock was the immediate solidification of the magma drawn directly from one common reservoir, they would represent the phases of differentiation in the parent magma at the time when the eruptions took place. If, however, the magma drawn from the reservoir did not solidify immediately, but remained in a molten condition within the fissure or conduit, a still further differentiation within this derived magma might take place under conditions imposed by its new environment. In this manner differentiation might proceed at quite different rates and possibly with diverse results in the parent magma and in the derived magma. Material, then, which, through subsequent eruption, might come to a place where it could solidify, might be derived from the parent magma or from the derived magma, and would represent different phases of differentiation. Either set of conditions of eruption may exist in nature, and much more complex ones. The first may very well be found in great fissure eruptions such as have taken place in western America. The second are probably represented by groups of volcanic vents. Both are simply modifications of eruptive processes, and differ in no essential respect.

The genetic relationship of rocks belonging to one center of eruption, or to one group of centers, or to one petographical province, makes plain the fortuitous character of so-called rock types ; the constitution of any rock mass depending primarily upon the phase of differentiation, and on the portion of the reservoir let out. It proves the fundamental character of the variability in composition of such rocks, both as between different bodies of rock and also within the mass of one continuous body in many cases. The degree of homogeneity in a rock body will depend upon the relation of its volume to that of the reservoir

from which it was drawn, and the conditions of differentiation existing there, and, further, upon whether it has undergone subsequent differentiation within itself.

The textural variations which were discussed in the first part of this paper, and which may exist in diverse portions of one rock body, or in different bodies of similar magmas, add still further to the complexities in solidified magmas. Rock magmas are thus known to vary frequently in chemical composition, mineral composition and texture. Names of rocks which are defined in terms of these three characters, can only apply to that portion of a rock body exhibiting the characters specified. Other parts of the mass will have different names, and to this extent be different rocks. The student should therefore recognize the difference in the idea conveyed by the term *rocks* as ordinarily used, and that which is involved in the expression *rock-body*, as a geological unit.

JOSEPH P. IDDINGS.

EDITORIALS.

THE December *Forum* contains an interesting article by Dr. D. G. Brinton on "The Beginning of Man and the Age of the Race." It affords, incidentally, several suggestions of value to geologists who are concerned in working out the problems which relate to the fossil relics of man on this continent. Dr. Brinton reasons that we have good grounds for locating man's birthplace only where mammals that are very near to him in physical prowess and mental aptitude are known to have existed some fifty or one hundred thousand years ago. This, he thinks, "at once excludes a large portion of the earth's surface, as the Arctic, Antarctic, and colder temperate zones, the lofty plateaus of the world and its inclement shores." "The whole of America must be excluded, for it shows no signs of having been the home of the higher mammals, that is, apes or monkeys without tails and with thirty-two teeth." By similar exclusions, the area of probable origin of man is limited to Southern Asia, Southern Europe, and Northern Africa. A fuller exposition of Dr. Brinton's views was given in his address before the American Association for the Advancement of Science at Madison iast August.

Without giving unqualified assent to all the limitations urged by Dr. Brinton, it would appear from the distribution of types kindred to man in the Pliocene and Pleistocene periods, and from the fact that the evolution of a naked animal from the hairy one can reasonably be supposed to have taken place only in a very warm climate, that primitive man, in the strict and proper sense of the term, can scarcely be supposed to have been an inhabitant of America. It is difficult to see how he could have reached this continent while in his strictly primitive state by land migration (even if there were land connection in the Behring region)

without traversing extensive cold and mountainous tracts quite prohibitory to a strictly primitive naked man of tropical origin, unless such transit were made in the early part of the Tertiary era before the development of cold northern climates and before the erection of the modern mountain systems. The early Tertiary, however, was an era of submergence rather than of elevation and land connection, and the possibility of such migration is extremely doubtful. Primitive man cannot well be supposed to have gained access to America by water until he had learned the art of navigation, or, in other words, until he had reached a somewhat advanced state of civilization. The strong presumption is, therefore, that man came to America only after he had attained to a stage of development much beyond the primitive one. It would appear that he must have become possessed of the power of protecting himself from the vicissitudes of climate and of securing the means of living under adverse conditions, or else had acquired the arts of navigation to an extent that would permit him to cross from the one continent to the other in warm latitudes.

As man's full evolution did not, therefore, probably take place on this continent, a complete series of relics of that evolution cannot be looked for here. Hence a system of interpretation of fossil relics which is based upon a theory of complete evolution here or which presumes the existence here of a complete series of relics does not carry inherent force, but rather the contrary. It is more probable that the oldest fossil relics of man on this continent represent, not a primitive, but some advanced stage of evolution. There is no inherent reason for expecting to find "paleolithic" or any other very primitive stage of culture here, however well demonstrated that stage may be on the eastern continent. To establish the existence of that stage here, unquestionable geological evidence, strong in itself and quite independent of theoretical support, must be produced. The geological problem in America will be greatly clarified when it is recognized that its solution must rest on strict stratigraphical and palæontological grounds, and not on any parallelism with a

theoretical evolution applicable only to the land of man's origin. The present stage of civilization is certainly not an immediate derivative of the next preceding, but has been imposed upon it unconformably, so to speak, and disjunctively. It is intrusive or superposed, and not derivative. So it is probable that the peculiar phases of the higher civilizations found in Central and South America were intrusive and not derivative. It is, therefore, not improbable that the entire succession of civilizations on the American continent consists of a series of intrusions or superpositions from the west and from the east, overlapping each other unconformably and disjunctively. They can, therefore, be worked out safely upon no theory of genetic succession. Each factor must be determined by means of its own inherent evidence. T. C. C.

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PROFESSOR JAMES D. DANA has a short article in the November number of the *American Journal of Science*[1] touching upon the recent discussion of the divisibility of the glacial period, in which he draws forth generalizations on two important lines, viz., (1) the personal attitude of writers on the subject, and (2) the difference between the glacial phenomena of New England and of the upper Mississippi basin. These seem to us to lie in the right direction, in the main, but in both cases to have somewhat missed the truest lines of distinction and to have fallen short of the most significant features. Professor Dana draws attention to the divergent views of New England and of western glacialists, and concludes that there must be some difference in the phenomena of the two regions to account for the differences of view. This seems to us very true and very important. The difference in the phenomena is, however, we think much more radical, and, at the same time, much more simple than that suggested by Professor Dana. It is, to our view, simply this: In New England only the latest epoch of the glacial period is distinctly repre-

[1] New England and the Upper Mississippi Basin in the Glacial Period. Am. Jour. Sci. III., Vol. XLVI., No. 275, Nov., 1893, pp. 327–330.

sented. The earlier episodes (to use a term not in controversy) may have representatives there in overridden and buried deposits, but, if so, they are obscure and have not been distinctly delineated. In the West, on the other hand, a very considerable series of episodes is well displayed. These embrace not only those presented in New England, but a considerable series of earlier ones not at all (distinctly) represented there. These greatly prolong and diversify the glacial series. In our judgment, it is not simply a doubling of that of New England, but a much higher multiplication. The whole series cannot, therefore, be judged by the incomplete New England representatives. All investigators, we think, or nearly all, agree that the New England glacial deposits fall within a relatively brief epoch and are not much (at least not very distinctly) differentiated. We agree heartily with those who would refer the declared New England drift to one epoch (reserving opinion, of course, regarding remnants of overridden or obscure drift of earlier episodes). New England is little better fitted to be a standard for the interpretation of the whole glacial series than it is for the whole Palæozoic series. In neither case is the series fully and distinctly represented, nor in either case is it typical. This is implied significantly in the relative state of delineation of the formations in the eastern and western sections. With a great preponderance of workers and of skill, no historical divisions of the glacial formations have yet been traced entirely across New England, not even those of an episodal rank. In the interior, on the other hand, something like a score of historical stages have been delineated over broad areas. Lines of episodal delimitation aggregating many thousands of miles have been mapped. Any attempt, therefore, to revise the work of the interior by the phenomena of New England is not likely to be more successful than the revision of the Palæozoic series on a like basis.

In classifying personal opinions, a dividing line separating the New England and the western workers is valuable and significant. But a much more significant cleavage plane, we think, may be found between those glacialists who have studied the

later episodes (or the earlier episodes) exclusively and those who have studied *both*. To have studied the Hudson River beds, east and west, is an inadequate preparation for deciding whether they are to be placed in a separate epoch from the Trenton beds or not. Both the Hudson River beds and the Trenton beds should be studied in regions where both are well displayed. So of the drift deposits. Classified on the basis of the *formational* distribution of critical studies, the true generalization falls easily into form, viz., those who have studied the formations of one epoch believe in one epoch; those who have studied the formations of more than one epoch, believe in more than one epoch.

The special individual opinion upon which Professor Dana lays stress ceases to have significance, or rather has its significance reversed, when it is observed that the studies on which it is based (most admirable in extent and in quality) fall almost exclusively within zones referred, by common consent, to a single, late, relatively brief glacial epoch.

Respecting the reference of the differences between the drift of the east and of the west to meteorological causes there is room here only for inviting attention to the pregnant fact that the greatest southward extension of the drift is found where the present meteorological and topographical conditions are least favorable. The drift of the interior reaches south of 38° latitude, that of New England only a little south of 41°, a difference that equals about three-fourths of the extent of New England in latitude, exclusive of Maine. The inferiority of the drift of New England in extent, in massiveness, and in serial development is the feature that calls for explanation in adverse conditions rather than the magnificent deployment of the glacial series on the plains of the interior. T. C. C.

REVIEWS.

RECENT CONTRIBUTIONS TO THE SUBJECT OF DYNAMOMETAMORPHISM FROM THE ALPS.

A. Heim: Geologie der Hochalpen zwischen Reuss und Rhein. Beiträge zur geologischen Karte der Schweiz, Vol. XXV., 4°: Bern, 1891, pp. 503.

C. Schmidt: Beiträge zur Kenntniss der auftretenden Gesteine. ib. Anhang, pp. 76.

L. Milch: Beiträge zur Kenntniss des Verrucano. Erster Theil : Leipzig, 1892, pp. 145.

M. P. Termier: Etude sur la Constitution géologique du Massif de la Vanoise. Bull. des Services de la Carte géol. de France. No. 20, Paris, 1891, pp. 147.

For many years both Huttonian (metamorphic) and Wernerian (original deposition) principles have been advanced to explain the crystalline schists of the Alps, as well as those of other regions. Because of their youth these great mountains are in many ways peculiarly fitted to throw light upon the difficult problems presented by these rocks. Many of the most classic Alpine localities are now being investigated by modern methods and are yielding welcome results which tend to establish not merely the fact, but also the nature, cause and processes of metamorphism.

Nowhere is this more true than in the region of vast earth-movements which Professor Heim of Zurich, has made the scene of his life work. As the result of his labors in this field, he was able to publish in 1878 his monograph on the Tödi-Windgälle group and the accompanying essay on the Mechanism of Mountain-making—a work which must certainly be regarded as epoch-making in suggesting the clue to a satisfactory explanation of the problems of regional metamorphism. This book Professor Heim now supplements with another of almost equal size, which contains the explanatory and descriptive text of the remainder of Sheet XIV. of the Geological Survey of Switz-

erland. This map, which was published on a scale of 1 : 100,000 in 1885, embraces the area between the St. Gotthard railway and the Rhein, north of the great central (Tessin) massif which forms the south flank of the Alps. Hence it includes the eastern portion of the Aar and Gotthard massifs, with all the younger formations in their most disturbed and implicated development. The thirteen years which have elapsed since the appearance of the earlier work have so greatly multiplied observations and stimulated thought that the standpoint regarding the whole subject of dynamic metamorphism is seen to be far advanced. Nor has Professor Heim himself been instrumental in any small way in bringing about this result. Aside from his own detailed field work, his suggestions as to the efficacy of orographic movement as a metamorphosing agent have been of profound and world-wide influence. Hence we cannot be surprised that he should have inspired enthusiastic students within the limits of his own special field. Others have worked out under his direction many details upon which some of his own broadest and most far-reaching generalizations rest. Some of the best of these results appear almost simultaneously with his latest work and form an integral portion of it. This is notably true of the special petrographic studies of both the eruptive and sedimentary rocks of two important and much discussed horizons—the Bündnerschiefer and the Verrucano—in both of which the processes of dynamometamorphism can be made out clearly and precisely followed.

More than one quarter of the Swiss atlas sheet XIV is occupied by that diversified complex of phyllites and schists, called by Heim the *Bündnerschiefer*. Their stratigraphical relations are, on account of the dislocations to which they have been subjected, often very obscure. They have been variously interpreted by different observers, but as the result of years of mature observation Professor Heim gives a full presentation of the facts, and now concludes that he must differ with Bonney, Gümbel, Diener and others who have ascribed to them a greater age, and agree with A. Escher v. d. Linth, Theobold and Rolle who regard them as a united and continuous series belonging in the main to the Lias. Toward the east, where these schists have their broadest and least disturbed development, they are comparatively little altered, and consist of calcareous shales and phyllites, impure limestones, sandstones, dolomitic and gypseous beds, interstratified with green schists and serpentine which are shown by microscopical exam-

ination to be altered volcanic material in conformable layers. Farther west, where these same rocks become tightly compressed between the gneisses of the central massifs, they have become recrystallized in proportion to the amount of their dislocation. "The study of the Bündnerschiefer," says Heim, "was that which years ago first convinced me of the possibility and reality of crystalline metamorphism being produced without the agency of eruptive contact, since I here for the first time observed how a belemnitiferous calcareous argillite became gradually more and more crystalline by the development of such minerals as mica, garnet, hornblende, zoisite, etc., at first as indistinct and imperfect nodules, and later as good crystals" (l. c., p. 52). The Bündnerschiefer, both in their less altered localities and in occasional beds, which have been by chance saved from metamorphism, are quite rich in Jurassic fossils.

About one-half of Professor C. Schmidt's appendix to Professor Heim's monograph is devoted to the petrographical description of the Bündnerschiefer, while the remainder treats of the crystalline rocks of the Aar, Gotthard and Adula massifs. A few preliminary remarks on the melaphyre of the Kärpfstock supplement the author's earlier communications with reference to the eruptives occurring in the Glarner double-fold.[1] The rocks from the three crystalline massifs are mainly the characteristic Alpine gneiss-granites or protogine, with dioritic or amphibolitic interpositions. Sericite- ottrelite- paragonite- zoisite-glaucophane-schists and eclogites also occur. The Adula gneiss is characterized by a green potash-mica (phengite) which is both uniaxial and biaxial. The rocks of the *Bündnerschiefer* are described by Schmidt under two principal heads: *a*) gray and black schists which are more or less completely metamorphosed sediments; and *b*), green schists which are foliated and metamorphosed eruptive material. Under the first division are mentioned schists with newly crystallized chloritoid, zoisite, tourmaline, epidote, biotite, muscovite, quartz, plagioclase and rutile. In some cases complete pseudomorphs of zoisite after echinoid remains are to be found. Other more tightly compressed beds at Nufenen, Val Piora, Lukmanier, Scopi, Ariolo, and other localities are still more highly crystalline, containing disthene, garnet, staurolite and similar minerals in abundance. These rocks have also been petrographically studied by Prof. U. Grubenmann.[2]

[1] Neues Jahrbuch für Min., etc., Beil. Bd. IV., p. 288, 1886. Ib., 1887, I., p. 58.

[2] Mitth. Thurgauischen Naturf. Gesellsch., Heft. VIII., 1888.

The second division or green schists include foliated gabbro, diabase, variolite, serpentine and various pyroclastic deposits now filled with new epidote, uralite, chlorite, saussurite and other secondary products. They show many points of analogy with the greenstone schist areas of the Marquette and Menominee districts on Lake Superior. Of more than usual interest are Schmidt's descriptions of the chloritic ferruginous oölite of Callovien. This was once a glauconitic oölite of Jurassic age, whose spherical particles have, by dynamometamorphism, been flattened, while their iron has crystallized as magnetite and hematite, and their glauconite changed to chlorite. The process of metamorphism in the Bündnerschists is summed up by Schmidt as follows: "The first stage of the metamorphism of the sediments always consists in the development of rutile microliths, as well as isolated and usually skeleton crystals whose nature depends on the composition of the metamorphosed material. These new phenocrysts gradually increase both in number and size; they are always filled with abundant inclusions of the groundmass whose sedimentary arrangement is not destroyed within the newly formed phenocryst. Finally, the clastic groundmass is transformed into an aggregate of crystalline minerals; and, where the metamorphism is most intense, the contrast between new phenocrysts and groundmass is least distinct." (l. c., p. 71.)

As a result of both his own and Schmidt's work, Heim concludes (l. c. p. 488): 1) that all the demonstrable orographic disturbance, and hence all the dynamometamorphism within his area, is post-Eocene, and much of it post-Miocene; 2) that two sorts of metamorphism must be distinguished. The recent dynamic metamorphism which was caused by, and hence was synchronous with orographic movement; and the much more ancient and probably still continuous metamorphism due to heat, moisture, and simple pressure without motion, which he calls *diagenetic* metamorphism (statical metamorphism of Judd). He contrasts the effects of mechanical metamorphism upon highly crystalline and sedimentary rocks, in that the same cause crushes the former into a finely granular schistose series, and recrystallizes the latter by developing large phenocrysts within them. He attributes these results in his particular Alpine region entirely to dynamic action, since he can find no trace of eruptive material which could have produced contact metamorphism in rocks of tertiary age.

The regret expressed by Professor Heim at the time of writin his text that no one had been found to thoroughly investigate th dynamic phenomena of the Verrucano seems about to be removed b the work now being published by Dr. L. Milch of Breslau. He ha recently offered as his *habilitationschrift* the first part of his petro graphical study of the Verrucano rocks of Graubünden, which deal with the historical development of the knowledge of this formation and the dynamic metamorphism of the eruptive rocks occurring in it. The second part, to be published later, will treat of the metamorphosed sediments and chemical aspects of the whole subject. The basic carboniferous eruptives of the region investigated are all melaphyres belonging to the three types: olivine-weisselbergite, navite and tholeiite; in other words old basalts. Some of them are well preserved, and show clearly the progressive effects of metamorphism with increasing mechanical disturbance. Some of the rocks are massive and others amygdaloidal, but the effect of the pressure is finally to destroy all of their original characters and to produce from them chloritic, epidotic, sericitic, or carbonate schists, which could just as well have originated from sediments of the proper composition. The mechanical action differentiates the originally homogeneous rock into portions of very different mineralogical composition, which in the most squeezed parts of a fold form fine parallel layers, but in the less compressed areas are intimately interlaced. Thus the same orographic force, while it may produce the same result from rocks genetically very distinct, can also, on the other hand, produce highly diverse rocks from one and the same mass.

The acid Carboniferous eruptives of the area studied are quart porphyries, or old rhyolites. Some of these form an important p of the pebbles in the Verrucano conglomerates, while others occu *situ* as a contemporaneous part of this formation. The latter r show many points of resemblance with the Windgälle porphyries, c sidered by Heim and Schmidt (N. J. B. BB. IV., 1886) as pre-Carb iferous. Milch distinguishes two categories of metamorphic chan exhibited by these acid eruptives. The first is mainly *mechanic* consisting of crushing and granulation, and producing fine-graine jaspery schists; the second is mainly *chemical*, producing serici from the feldspathic constituents which forms interlacing men branes. There is then here observable a complementary relatic between the mechanical and chemical work of dynamometamorphism

like that pointed out by the present writer in the greënstone-schists and associated rocks of Lake Superior. (Bull. U. S. Geol. Surv., No. 62).

Professor Termier of the Ecole des Mines at Saint-Etienne has given in his essay on the constitution of the Vanois massif in Savoy, another excellent contribution to our knowledge of the effects of orographic movement in metamorphosing Alpine sediments of Caboniferous and Triassic age. This is all the more welcome from France where dynamometamorphism has been rather slow to gain recognition, in spite even of the convicting demonstrations by Gosselet in the Ardennes. The *schistes lustrés*, which bound the Vanois massiv on the east, considered by Lory as upper Triassic, are made by Termier pre-Carboniferous. The principal horizons which have been studied with reference to metamorphism are the Permian and Trias. The former is represented mainly by quartzites and phyllites, altered and recrystallized in proportion to the disturbance they have suffered. In the phyllites rutile, sphene, tourmaline, garnet, zoisite, epidote, glaucophane, chloritoid, various micas and feldspars, and quartz have been abundantly developed. Many interesting details and figures are given to illustrate the development of these new minerals. Albite crystals by their growth in the phyllite have sometimes displaced all, or only a part of the original schist constituents, while in other cases they have not disturbed their position at all. Various minerals are traced in their gradual development from indistinct nodules to perfect crystals. Only the metamorphism of sedimentary beds is considered, and the general conclusion is reached that their alteration is independent of eruptive action, and entirely conditioned by the heat produced by orographic movements. This heat is supposed to have been very gradually produced and very slowly dissipated. The author thinks that a temperature of 200 to 250 C., continued through ages, would suffice to crystallize new compounds like feldspar, quartz, carbonates, tourmaline, chlorite, micas, ilmenite, rutile, etc., without affecting the bulk composition of the rock. In exceptional cases an intenser movement might give a temperature of 300 C., sufficient to produce amphibole, which will appear as glaucophane, if, as in his Permian beds, the original sediments are very rich in soda.

GEORGE H. WILLIAMS.

Text Book of Geology: By SIR ARCHIBALD GEIKIE, F.R.S. Third edition, revised and enlarged. Pp. i-xvi, 1147.

The preface to the third edition of this standard text-book states that it has been entirely revised and in some portions recast and re-written, so as to bring it abreast of the continuous advance of geological science.

A careful comparison of the third edition with the second indicates that this claim is fully warranted. The general plan of the volume is unchanged, but there are few discussions in which modifications do not appear. In many places the changes consist of nothing more than the addition or modification of a sentence or a paragraph. Even these minor modifications and additions are of great value, since in them are embodied many of the newer facts and ideas which recent research has developed. Thus we find the newer estimates of the average elevation of the continents; new suggestions concerning the age of the earth; the introduction of new descriptions of minerals of petrographical importance, and the modification of some upon which new light has been thrown by recent investigations; the adoption of Rosenbusch's terms for certain rock structures; the use of the word megascopic in place of macroscopic; a re-arrangement of rocks upon a genetic basis, as sedimentary, massive or eruptive, and schistose or metamorphic, and a better subdivision under these heads; throughout the descriptions of rocks, additions and improvements incorporating the more essential facts brought out in recent publications. The possibility of the metamorphic origin of some granites is minimized, and the probability that the greater number of them are eruptive is emphasized; the processes of metamorphism are elaborated, and the kinds of mineralization of common occurrence are pointed out. We find, too, new facts as to the amplitude of earthquake waves; the results of the more recent mathematical calculations concerning the distortions of the sea level by the attractive influence of land elevations; fuller statements as to the possibility of changes of sea level, and concerning the causes of oscillations of the level of land and sea; the conclusions to which experiment has led concerning the effect of hot water on the fusion temperature of rock; new ideas concerning the flow of rock as the result of crushing and pressure; clear cut statements growing out of recent discussions concerning the efficiency of glacial erosion; a multitude of facts at one point and another drawn from the reports of the Challenger, and from the reports of other deep

sea exploring expeditions, as to sedimentation far out from land; the results of recent biological investigation touching the supply of lime carbonate and silica from which animals and plants secure materials for their shells; a more explicit statement than the earlier edition contained concerning the complexity of the glacial period; a modification of the classification of geological formations of North America, incorporating the ideas of the correlation essays of the United States Geological Survey, etc., etc. The additions and changes concerning these topics fairly represent the character of the alterations to be found throughout the volume. These new touches are sufficiently numerous and suggestive to make the volume valuable, even to those already in possession of the earlier edition.

At a number of points the changes have been much more considerable. Thus twelve pages were devoted to the discussion of the Archean in the old edition, while thirty-seven pages are given to the pre-Cambrian in the new. The general character of the changes at this point were foreshadowed in an article by Sir Archibald in the first number of this journal. Two groups of pre-Cambrian rocks are distinctly recognized, the lower consisting of gneisses and schists, and the other of the pre-Cambrian sedimentaries and volcanics. The character, the relations, and the genesis of these groups is briefly but comprehensively set forth. Concerning the first group the conclusion reached, as expressed in the author's own words, is as follows:

"These rocks are in the main various forms of original eruptive material, ranging from highly acid to highly basic; they form in general a complex mass belonging to successive periods of extrusion; some of their coarse structures are probably due to a process of segregation in still fluid or mobile, probably molten, material consolidating below the surface; their granulitized and schistose characters, and their folded and crumpled structures point to subsequent intense crushing and deformation; their apparent alternation with limestone and other rocks, which are probably of sedimentary origin, are deceptive, indicating no real continuity of formation, but pointing to the intrusive nature of the gneiss."

Concerning the second group of pre-Cambrian rocks, the sedimentary and volcanic series, Sir. Archibald takes the same position as in the article already referred to[1] and essentially the same position as that of Prof. Van Hise, already set forth in this journal[2] and elsewhere.[3]

[1] This Journal, Vol. I., p. 1.

[2] Vol. I., No. 2, p. 123.

[3] Bulletin 86, United States Geological Survey.

The adoption of any general terminology for the pre-Cambrian rocks is deprecated. In the author's judgment, " the term Laurentian cannot henceforth have more than a local significance." He further indicates his belief that "there will be much less impediment to the progress of investigation by the multiplication of local names than by the attempt to force indentifications for which there is no satisfactory basis. Each country will have its own terminology for pre-Cambrian formations, until some way is discovered of correlating these formations in different parts of the globe." The great duration of the time interval represented by the pre-Cambrian sedimentaries and their great unconformities is distinctly recognized. Much fuller details are given in this than in any earlier edition, concerning the development of the pre-Cambrian in different parts of the world. On the whole, the chapter on pre-Cambrian is much more satisfactory than in any other existing text-book. Several other periods are much more fully dealt with in this edition. This is especially true of the Silurian and Tertiary. Various new figures of fossils are introduced, representing important species of recent discovery.

In the section dealing with glacial geology, we notice that no distinction is made between the formations known in America as kames and osars, and are a little surprised to find the statement concerning kames (osars as we know them in America) that "no very satisfactory statement of their mode of origin has yet been given." Perhaps this may be true in a restricted sense, since there is much discussion as to the exact character of the streams which produce them, but that the formations which we have come to call osars were produced chiefly by superglacial or subglacial streams, does not seem to admit of serious question, so far as America is concerned. We are also surprised to find the loess placed in the recent or post-glacial series. This is not the correct reference of most of the loess in the United States, for at various points along the northern border of the very extensive loess covered area, as in Illinois and Iowa, the loess is frequently found beneath the till of the later ice invasions. The eolian theory of the origin of the loess is favored. This seems to be by far the most satisfactory theory for the Asiatic loess, and is finding much favor in connection with the loess of Europe. It is doubtless the loess of these countries to which reference is especially made. But the points urged in support of the eolian theory are not all applicable to the American formation. For example, "the thoroughly oxidized condition" of the iron content of the loess

cannot be urged in support of its eolian origin on this side of the Atlantic. Where the loess of the United States is typically developed, and has any considerable thickness, its iron content is not often thoroughly oxidized below a depth of four to six feet. The same is true of the loess of some parts of Germany. So, too, it may be much more troublesome to account for the presence of even a few aquatic shells in an eolian deposit, than for the presence of many land shells in a water deposit. The frequent inter-stratification of loess and sand at the base of the formation, the occasional presence in the loess of stone quite beyond the power of wind to transport, its general habit of following river courses, the presence of aquatic shells, and its lack of oxidation and leeching except for a short distance from the surface, are considerations of sufficient weight to make it very doubtful if the larger part of the American loess can be due to the wind. On the other hand, we believe that some (quantitatively a small part) of the loess of the United States is unquestionably of eolian origin. It has long seemed possible to the writer that formations may have been grouped together under this name which have had very different origins at very different times. This notion is emphasized in the volume before us, where the adobe of the United States, two or three thousand feet thick, is referred to as the loess, though this is not the formation commonly known as loess, and can hardly be one with it in origin. Many new facts are given concerning glaciation in regions where the work of the ice has not, until recently, been known.

The incorporation of the great body of new facts and suggestions throughout the volume has meant the digestion of a large body of recent literature. Indeed, there appears to have been very little geological literature produced since the earlier edition of the work of which the author has not made use, and to which we do not find explicit reference in the new edition.

ROLLIN D. SALISBURY.

Bodengestaltende Wirkungen der Eiszeit. Vortrag von DR. AUG. BÖHM, *Privatdocent an der k. k. technischen Hochschule*, Vienna.

The difficulty of finding satisfactory summaries of the physical features of European countries makes such essays as the above especially welcome to the American student, particularly if he contemplates a trip abroad. The essay is one of a series of lectures, published by

the *Verein zur Verbreitung naturwissenschaftlicher Kenntnisse* in Vienna now in its thirty-third year. The essays may be had separately, and table of contents of the thirty odd volumes may be procured from th publisher, Hölzel, for a nominal price ; from this one may select suc numbers as he wishes. Recent volumes contain articles by Suess *Ueber die Structur Europas*, from which the geological traveler ma gain a breadth of view that will greatly profit him ; by Penk, on *D Oesterreichische Alpenvorland*, and *Die Donau* (Danube), from whic more local views may be gathered of equal value in closer studie Dr. Böhm's essay is a well-argued presentation of the belief that ev the greater Swiss lakes, as well as nearly all the smaller ones, are t result of glacial erosion. He justly emphasizes the moderate prop tion of depth to length in even the deepest of the marginal lakes ; a the location of these lakes with respect to the greater glacier whi formerly emerged from the Alpine valleys on the Piedmont distric Even in those valleys where no marginal lakes now exist, as in the vall of the Lech, Inn, Salzach, and others, rivers emerging from the nor eastern Alps, there have recently been lakes, but their basins are n filled and drained by the active streams that traverse them. The hi level lakes, held in rock basins and enclosed by mountain cirq (Karen), are with even more confidence ascribed to glacial acti Many of the smaller lakes have been extinguished already since glacial period. In the Tyrol, no less than 118 lakes recorded on maps of the last century, are now drained. In this relation, the Alpi valleys seemed to have advanced further towards recovery from glacial accident to which they have been subjected than the Norwegi streams; for in Norway, many a river is still only a string of lak It is notable that drumlins are not mentioned by Dr. Böhm as ch acteristic products of glacial action ; hence we must infer that they seldom seen in Continental Europe.

WM. M. DAVIS.

ANALYTICAL ABSTRACTS OF CURRENT LITERATURE.

Conditions of Appalachian Faulting. By BAILEY WILLIS and C. WILLARD HAYES. (Amer. Jour. of Sci. Vol. XLVI., pp. 257–269).

The cross section of a great mass of sediments accumulated over a zone parallel to the shore is that of a bi-convex lense. One edge rests against the shore from which the mass at first thickens rapidly and then thins gradually seaward. A broad shallow trough is thus formed by the deeper strata which may be called an original syncline. The authors give data to show that previous to compression such original synclines of deposition existed in the paleozoic strata of the Appalachians in Pennsylvania, east Tennessee, northwest Georgia, Alabama and in other localities.

In the original synclines of the Appalachian province the steeper seaward dip was northwestward and the gentler shoreward dip was southeastward. If strata in such a position be subjected to sufficient compressive force, the original syncline will be exaggerated and the steeper shorter arm will be rotated as between the forces of a couple. If compression is continuous long enough the beds may be overturned.

From this stepfold a thrust-fault may develop in either of three ways. The pressure tending to exaggerate the fold is most efficiently transmitted by the most massive stratum, and any condition which weakens this stratum may lead to a fault. The three conditions under which this massive stratum may be weakened are erosion, fracture, plastic flow; the second being the most common in the Appalachian region, where the massive stratum seems to have fractured, forming thrusting faults under loads of 2,800 to 11,000 pounds per square inch, but to have folded without breaking under loads of 11,000 to 34,000 pounds per square inch.

The authors discuss with the aid of diagrams the mechanics of repeated parallel folds, and show that the parallel folds are later than that located by the original syncline, and are consequent each upon the next preceding it in time and position. In the Appalachians the compressing force was directed both northwestward and southeastward. But when folding began there was a movement from the force towards the resistance. This the authors conceive to have been a superficial flow of a broad zone from northwest to southeast, from the sea towards the land.

H. B. K.

Ueber Geröll-Thonschiefer glacialen Ursprungs in Kulm des Frankenwaldes. By ERNST KALKOWSKY in Jena (Zeitschrift der Deutschen geologischen Gessellschaft. XLV. Band. 1. Heft. Januar, Febuar und Marz, 1893, pp. 69–86.)

In the midst of the shales and greywackes of the Upper Kulm of Frankenwald, there is a peculiar sort of conglomerate (*geröll-thonschiefer*). This conglomerate is exposed at but few points. It is not certain that all the exposures belong to one horizon, though nothing is known which forbids this conclusion. The demarkation of the conglomerate from the underlying and overlying beds is sometimes, but not always, distinct. The conglomerate has a known thickness at one point of at least 18 m. It is wholly unstratified, and is made up of something like equal parts of clayey matter, and well-rounded stones (*geröllen*). The sand grains are conspicuously angular, while the larger stones are as distinctly well-rounded. In no case do the sandy or stony materials show any traces of arrangement suggestive of stratification. The stony material varies in size from pebbles to small boulders, the largest being 22 × 29 × 12 c. m. In connection with these limitations in size it must be remembered that the exposures are very limited. While it is difficult to determine the origin of the stony material in all cases, it does not seem necessary to suppose that it is of very distant origin. The author considers the various possibilities concerning the origin of this conglomerate, and concludes that it is the work of rivers which were affected by floating ice. The conglomerate is therefore an indication of cold climate in the adjacent regions at the time of its formation. The author thinks that the Carboniferous ice period, belief in which seems not to be without foundation, may be brought into connection with the cold climate indicated by this conglomerate bed in the upper Kulm. He further thinks that the cold climate of the Kulm may have made itself felt over wide areas, since more or less extensive conglomerate beds of this age occur in widely separated parts of the German Empire.

R. D. S.

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